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Broadband Fan Noise Prediction System for Turbofan Engines

Volume 3: Validation and Test Cases

Bruce L. Morin
Pratt & Whitney, East Hartford, Connecticut

November 2010

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Summary

Pratt & Whitney has developed a Broadband Fan Noise Prediction System (BFaNS) for turbofan engines. This system computes the noise generated by turbulence impinging on the leading edges of the fan and fan exit guide vane, and noise generated by boundary-layer turbulence passing over the fan trailing edge. BFaNS has been validated on three fan rigs that were tested during the NASA Advanced Subsonic Technology Program (AST). The predicted noise spectra agreed well with measured data. The predicted effects of fan speed, vane count, and vane sweep also agreed well with measurements.

The noise prediction system consists of two computer programs: Setup_BFaNS and BFaNS. Setup_BFaNS converts user-specified geometry and flow-field information into a BFaNS input file. From this input file, BFaNS computes the inlet and aft broadband sound power spectra generated by the fan and FEGV. The output file from BFaNS contains the inlet, aft and total sound power spectra from each noise source.

This report is the third volume of a three-volume set documenting the Broadband Fan Noise Prediction System:

Volume 1: Setup_BFaNS User's Manual and Developer's Guide
Volume 2: BFaNS User's Manual and Developer's Guide
Volume 3: Validation and Test Cases

The present volume begins with an overview of the Broadband Fan Noise Prediction System, followed by validation studies that were done on three fan rigs. It concludes with recommended improvements and additional studies for BFaNS.

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Broadband Fan Noise Prediction System for Turbofan Engines
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1.0 Introduction

In early turbofan engines, the fan blade passage tone and higher harmonics dominated the fan noise level when compared to fan broadband noise. However, engine makers have been very successful at reducing fan tone noise by decreasing fan tip speed, providing ample spacing between airfoil rows, carefully selecting the airfoil counts, and acoustically treating the fan duct. In fact, tone noise reduction has been so great that fan broadband noise is now a major contributor to the overall engine noise level. Under NASA funding, Pratt & Whitney has developed a Broadband Fan Noise Prediction System (BFaNS) for turbofan engines. This prediction system is built around acoustic theories developed by Hanson (Refs. 1 to 4) and Glegg (Refs. 5 to 7). These theories account for noise generated by turbulence impinging on the leading edges of the fan and fan exit guide vane (FEGV), and noise generated by boundary-layer turbulence passing over the fan trailing edge. Figure 1 shows the fan broadband noise sources that can be predicted with BFaNS.

This report documents the validation studies that were performed on the following three fan rigs:

- Pratt & Whitney 22 in. diameter fan tested in the NASA Glenn Research Center 9- by 15-ft Low Speed Wind Tunnel
- General Electric 22 in. diameter fan tested in the NASA Glenn Research Center 9- by 15-ft Low Speed Wind Tunnel
- Boeing 18 in. diameter fan tested at Boeing Low Speed Aeroacoustic Facility (LSAF)

Volume 1 of this report series provides instructions for running Setup_BFaNS, and Volume 2 provides instructions for running BFaNS.

2.0 Pratt & Whitney 22-in. Diameter Fan

This section describes the validation of BFANS using data acquired from a P&W 22-in. fan (designated Fan no. 1) that was tested in the 9- by 15-ft Low Speed Wind Tunnel at NASA Glenn Research Center. The experimental data consisted of farfield noise, Laser Doppler Velocimeter (LDV) and hot-wire (HW) measurements of the mean velocity and turbulence near the stator leading edge, and total-pressure and total-temperature profiles downstream from the fan.

The flow-field measurements were used in conjunction with CFD calculations to provide the input needed to run BFaNS. The BFaNS validation was done at three speeds corresponding to approach, cutback, and sideline power. The BFANS calculations were compared to experimental data in terms of total sound power spectra.

2.1 Acoustic Configuration

Figure 2 shows the fan configuration that was used during the acoustic tests. The rotor had a diameter of 22 in. and consisted of 18 blades. The stator configuration consisted of 45 radial vanes. Reference 8 provides a more detailed description of the acoustic setup and measurements. Appendix A provides a detailed description of the flow path, blade and vane geometry.

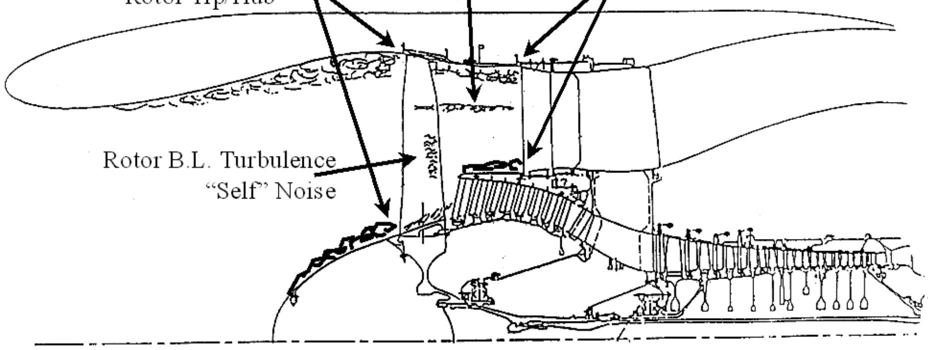


Figure 1.—Fan broadband noise sources predicted by BFaNS.

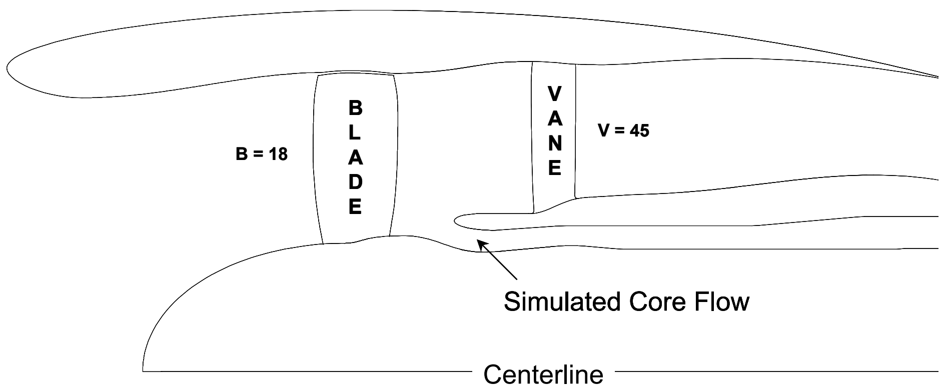


Figure 2.—Acoustic configuration, P&W fan.

2.2 Flow-Field Measurement Configuration

To facilitate the LDV and hot-wire measurements, the stator was moved 2.33 in. downstream from its nominal location as shown in Figure 3. This modification permitted velocity measurements to be obtained 2.65 and 6.67 in. downstream from the fan tip trailing edge (Stations A and B, respectively). Note that Station A is upstream and Station B is downstream from the nominal location of the stator leading edge in the acoustic configuration (approximately 5.10 in. downstream from the rotor). Though not shown, a bellmouth inlet was installed during all LDV and hot-wire tests. Table 1 lists the LDV and HW data that were used in the present study (shaded cells indicate conditions where data was not acquired).

Appendix A shows plots of the mean and turbulent flow-field measurements acquired at Stations A and B. References 9 and 10 provide additional information on the flow-field data, along with preliminary BFaNS predictions.

TABLE 1.—HOT-WIRE AND LDV DATA USED IN PRESENT STUDY, P&W FAN

Corrected fan speed (rpm)	Acoustic condition	HW data at station A	HW Data at station B	LDV data at station A	LDV data at station B
5425	Approach	Yes	Yes	Yes	Yes
7525	Cutback	----	Yes	No	Yes
8750	Sideline	Yes	Yes	Yes	Yes

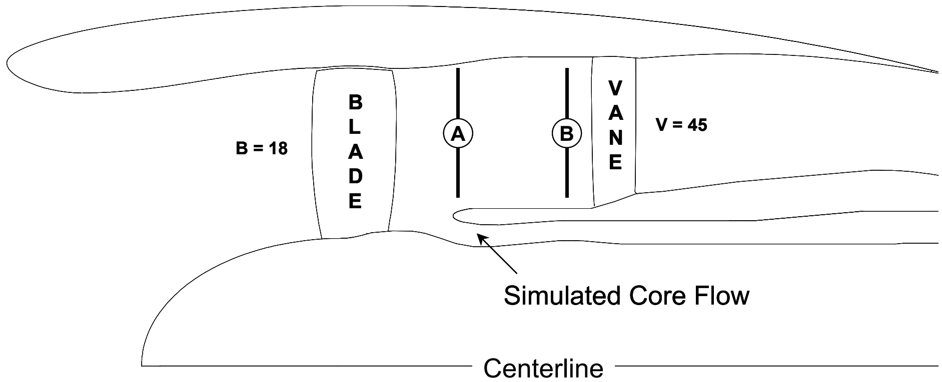


Figure 3.—Flow-field measurement configuration, P&W fan.

2.3 Approach Power

Figure 4 shows calculated and measured sound power spectra at approach power. The calculations and measurements have been scaled to an 81-in. diameter fan. The calculations were done using LDV and HW data acquired at Stations A and B (hence, there are four calculated spectra). Recall that Station A is upstream from the vane leading edge, and Station B is downstream from the vane leading edge (see Figure 2 and Figure 3). The calculations in Figure 4(a) exclude blade noise, while those in Figure 4(b) include blade noise.

The calculated spectra in Figure 4(a) show good agreement with the measured data. Across most of the frequency range, the measured spectrum falls between the upper and lower limits of the calculated spectra. However, when blade noise is included (Figure 4(b)), the calculated spectra exceed the measured spectrum over most of the frequency range. These results suggest that BFaNS over-predicts the contribution of blade noise (mainly self noise) relative to vane noise.

Figure 4 also shows that the noise calculations based on HW data are approximately 3 dB greater than those based on LDV data. This result is consistent with the velocity profiles in Appendix A, which show that the HW measured a larger mean velocity than the LDV. Ideally, these two techniques should measure the same profile since the operating conditions were nominally the same between the two tests. Based on correspondence with NASA personnel (Ref. 11), the LDV data is believed to be the most accurate, and the hot-wire data should only be used to determine the turbulent length scale.

2.4 Effect of Fan Speed

Figure 5 shows calculated and measured sound power spectra at approach, cutback and sideline power. The calculations and measurements have been scaled to an 81-in. diameter fan. The calculations are based on the average of the calculations made with the LDV data at Stations A and B (the HW data was used to determine length scale only). The calculations in Figure 5(a) exclude blade noise, while those in Figure 5(b) include blade noise.

In general, the calculated spectra in Figure 5(a) show good agreement with the measured data, in terms of both level and shape. However, the calculated spectra do not exhibit the subtle "double-hump" that is observed in the measured spectra. In Section 3.0, it will be shown that this "double hump" indicates two separate noise sources; the first hump is associated with vane noise, and the second hump is associated with blade noise. When blade noise is included in the calculations (Figure 5(a)), the calculated spectra are significantly greater than the measured spectra, especially at the high-frequency end of the spectra. Again, this suggests that BFaNS over-predicts the contribution of blade noise relative to vane noise.

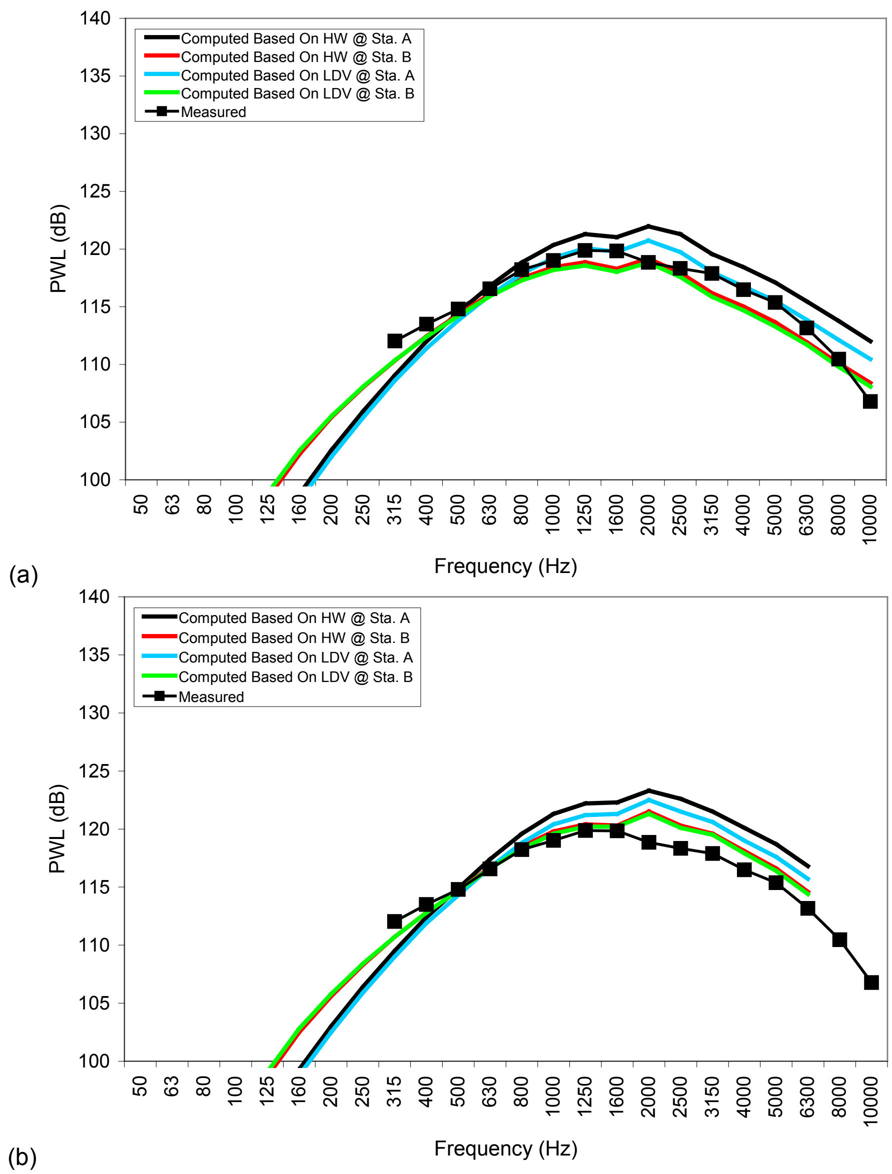


Figure 4.—Sound power spectra, approach power, P&W fan no. 1. (a) Calculations excluding blade noise. (b) Calculations including blade noise.

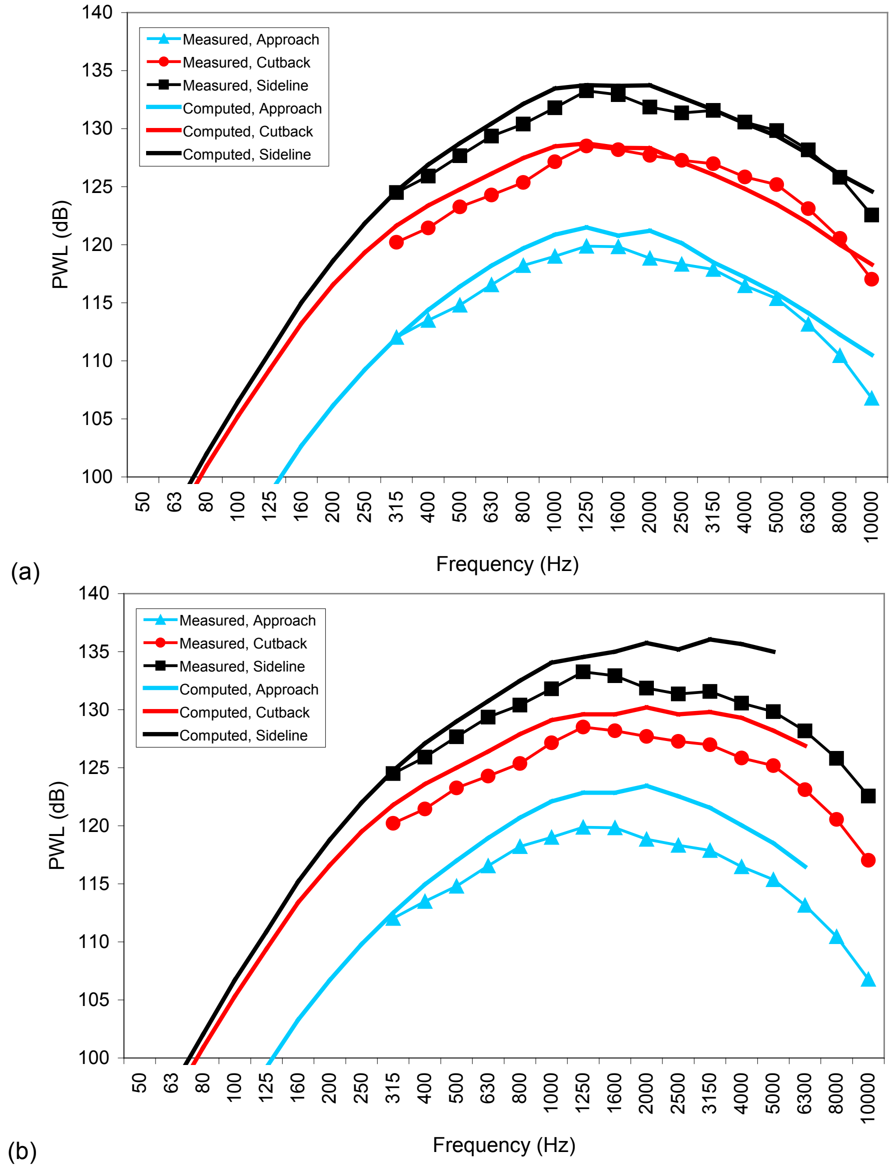


Figure 5.—Effect of fan speed, P&W fan no. 1. (a) Calculations excluding blade noise. (b) Calculations including blade noise.

3.0 General Electric 22-in. Diameter Fan

This section describes the validation of BFANS using data acquired from a GE 22-in. fan (designated R4) that was tested in the 9- by 15-ft Low Speed Wind Tunnel at NASA Glenn Research Center. The experimental data consisted of farfield noise, Laser Doppler Velocimeter (LDV) and hot-wire (HW) measurements of the mean velocity and turbulence near the stator leading edge, and total-pressure and total-temperature profiles downstream from the fan. Extensive documentation of the testing can be found in References 12 through 18.

The flow-field measurements were used in conjunction with CFD calculations to provide the input needed to run BFaNS. The BFaNS validation was done at three speeds corresponding to approach,

cutback, and sideline power. The BFANS calculations were compared to experimental data in terms of total sound power spectra.

3.1 Acoustic Configurations

Figure 6 shows the fan configurations that were used during the acoustic tests. The rotor had a diameter of 22 in. and consisted of 22 blades. The stator configuration consisted of 54 radial vanes, 26 radial vanes, 26 swept vanes or no vanes. Reference 15 provides a more detailed description of the acoustic setup and farfield noise measurements. Appendix B provides a detailed description of the flow path, blade and vane geometry.

3.2 Flow-Field Measurement Configuration

Figure 7 shows the experimental setup used for the LDV and hot-wire measurements. All LDV and HW data was acquired with the 26-swept-vane configuration. The HW stations were 2.96 and 5.89 in. downstream from the fan trailing edge tip (denoted HW-A and HW-B, respectively). The LDV stations were 3.12 and 6.49 in. downstream from the fan trailing edge tip (denoted LDV-A and LDV-B, respectively). The downstream HW and LDV stations are close to the leading edge of the radial vanes. Table 2 lists the LDV and HW data that were used in the present study (shaded cells indicate conditions where data was not acquired). Note that hot-wire data acquisition was limited to the approach speed and below due to durability problems with the hot wires. Consequently, BFaNS could not be run at cutback or sideline power due to the absence of measured turbulence length scales.

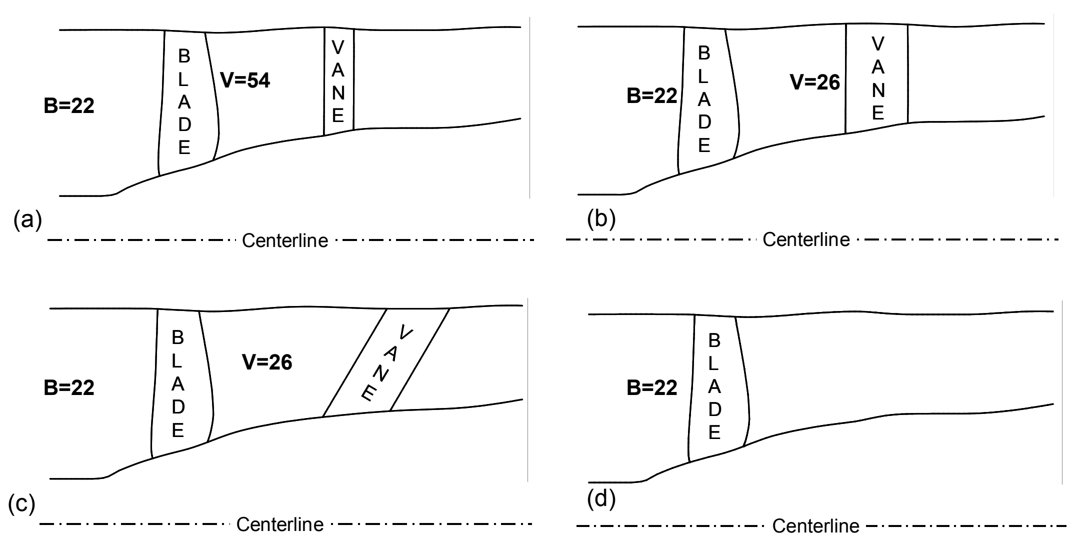


Figure 6.—Acoustic configurations, GE fan: (a) 54 radial vanes (baseline); (b) 26 radial vanes; (c) 26 swept vanes; and (d) rotor alone.

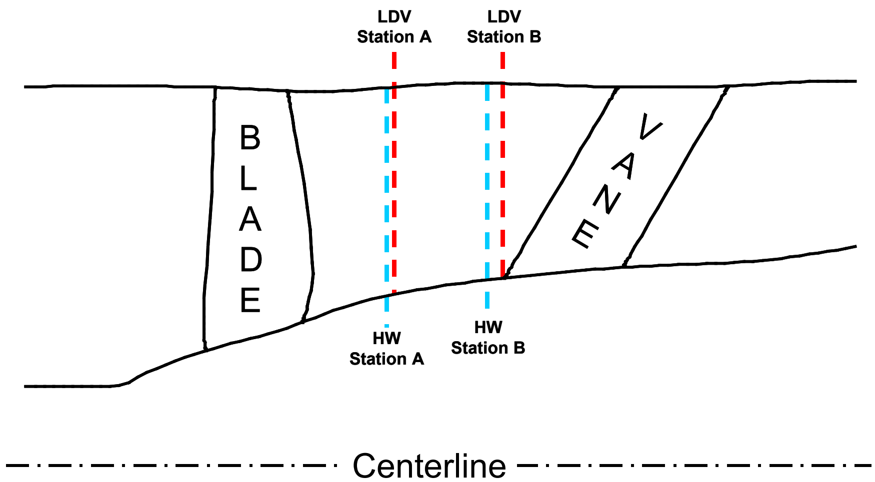


Figure 7.—Flow-field measurement configuration, GE fan.

TABLE 2.—HOT-WIRE AND LDV DATA USED IN PRESENT STUDY, GE FAN

Percent design speed	Corrected fan speed (rpm)	Acoustic condition	HW data at station A	HW data at station B	LDV data at station A	LDV data at station B
50	6329	---	No	No	No	No
61.7	7808	Approach	Yes	Yes	Yes	Yes
87.5	11074	Cutback	---	---	No	No
100	12657	Sideline	---	---	No	No

Appendix B shows plots of the mean and turbulent flow-field measurements acquired at HW and LDV Stations A and B. References 13 and 18 provide a detailed description of the HW and LDV data acquired.

3.3 Approach Power, 54 Radial Vanes

Figure 8 shows calculated and measured sound power spectra at approach power for the 54-radial-vane configuration. The calculations and measurements have been scaled to an 81-in. diameter fan. The solid black line excludes blade noise, while the solid red line includes blade noise. The calculated spectra are the average of the calculations made with the HW-B and LDV-B data. Unlike the calculations for the P&W fan, there was negligible difference between the calculations made with HW or LDV data for the GE fan.

The results for the GE fan are similar to those for the P&W fan. Without blade noise, the calculation is in good agreement with the measured spectrum. With blade noise, the calculation exceeds the measured spectrum, especially at high frequencies (though the overprediction is much less for the R4 fan compared to the P&W fan).

Figure 9 shows calculated and measured sound power spectra at approach power for the rotor-alone configuration. The calculations and measurements have been scaled to an 81-in. diameter fan. The flow-field input used for the rotor-alone noise calculation was obtained from CFD predictions provided by NASA. The red line indicates rotor self noise, and the blue line indicates rotor turbulent inflow noise. For reference, the 54 radial-vane data is included in the figure.

The experimental data shows that the rotor-alone noise is within 3 dB of the 54-radial-vane noise at frequencies greater than 5 kHz (i.e., the rotor is more important than the vane at 5 kHz and above). This explains the subtle “double hump” in the 54-radial-vane noise spectrum. The first hump is associated with vane noise, while the second hump is associated with blade noise. Note that the rotor self-noise calculation agrees fairly well with the measured rotor-alone data. Also, based on the calculations, the rotor turbulent inflow noise is much less important than the rotor self noise.

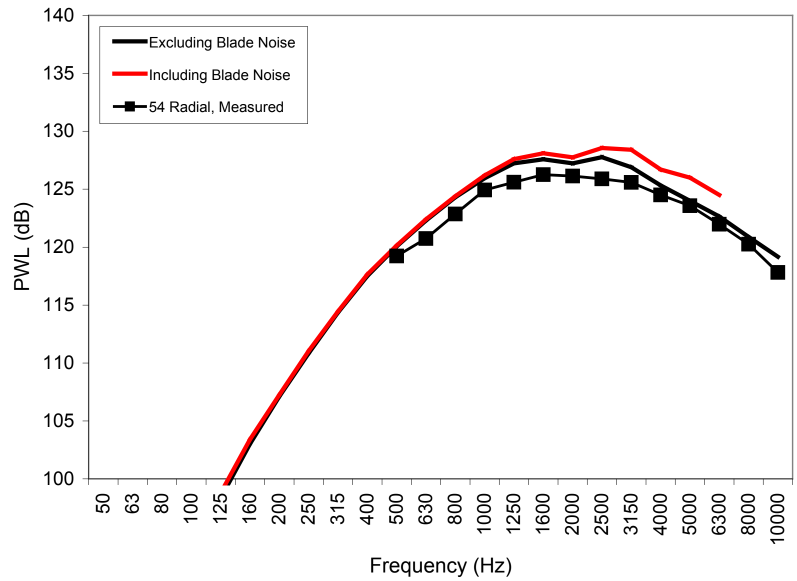


Figure 8.—Sound power spectrum, GE R4 fan, 54 radial vanes (approach power).

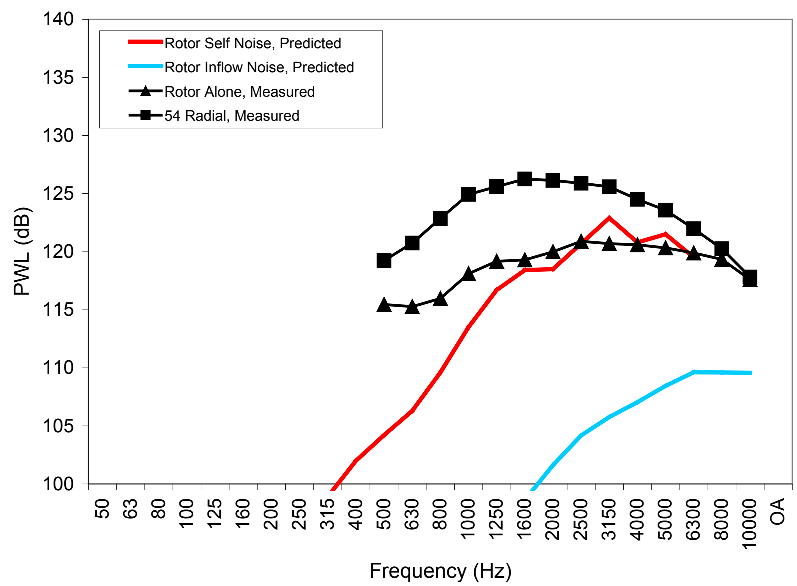


Figure 9.—Sound power spectrum, GE R4 fan, rotor alone (approach power).

3.4 Effect of Vane Configuration

Figure 10 shows calculated and measured sound power spectra at approach power for the 54-radial-vane, 26-radial-vane and 26-swept vane configurations. The calculations and measurements have been scaled to an 81-in. diameter fan. The calculations in Figure 10(b) exclude blade noise, while those in Figure 10(c) include blade noise. In general, the calculations demonstrate the same trend as the experimental data. However, without blade noise, the calculations are more sensitive to the vane configuration than the experimental data. With blade noise, the calculations are less sensitive to vane noise than the experimental data. These results indicate that BFaNS correctly models the physics of noise generation, but may not be able to capture the relative contributions of blade and vane noise.

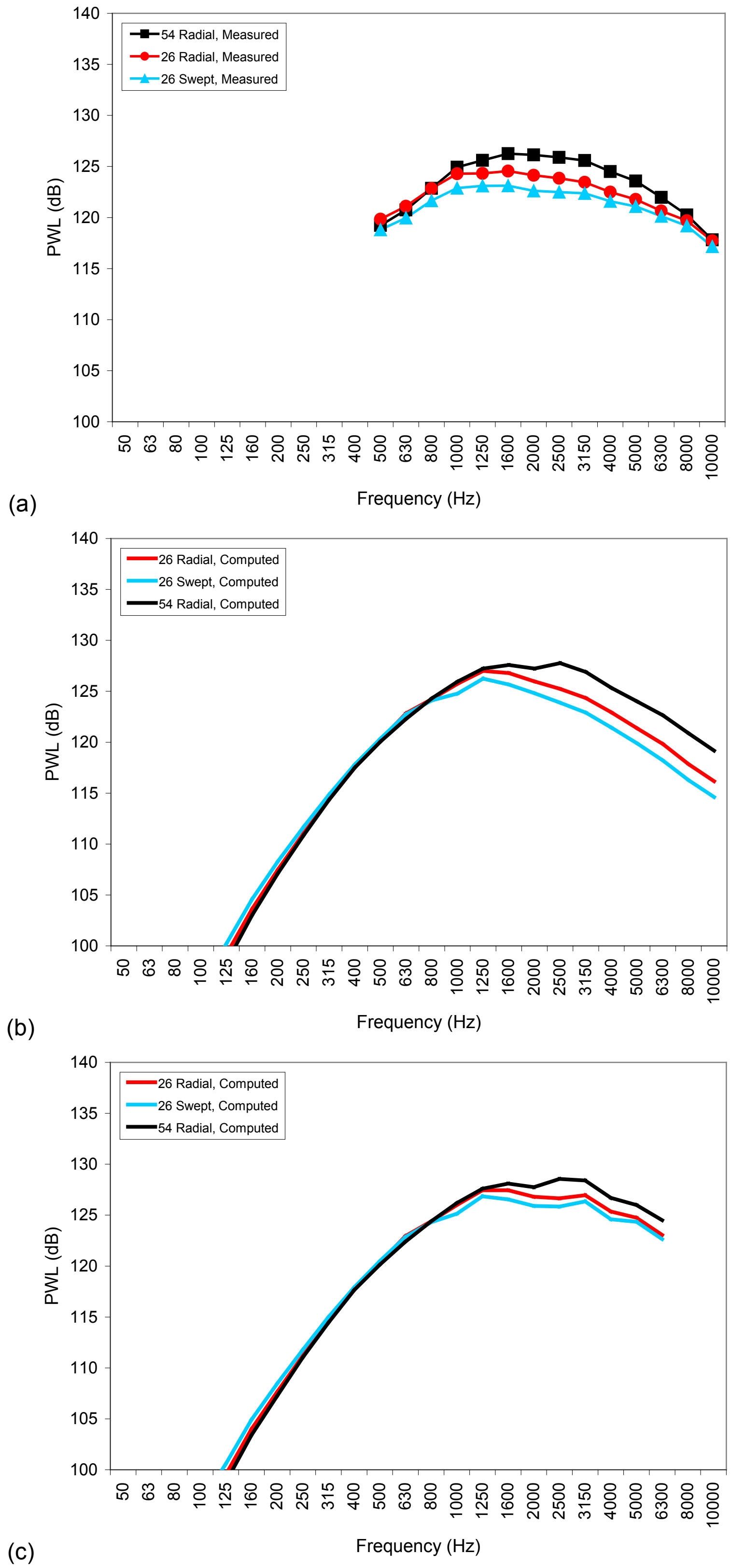


Figure 10.—Effect of vane configuration: (a) Experimental data; (b) Calculations excluding blade noise; and (c) Calculations including blade noise.

4.0 Boeing 18-in. Diameter Fan

This section describes the validation of BFANS using data acquired from a Boeing 18-in. fan that was tested in Boeing's Low Speed Aeroacoustic Facility (LSAF). The experimental data consisted of farfield noise, hot wire (HW) measurements of the mean velocity and turbulence near the rotor and stator leading edges, and total-pressure and total-temperature profiles downstream from the fan. Detailed documentation of the testing is provided in Ref. 19.

The BFaNS validation was done at three speeds roughly corresponding to 55, 70 and 88 percent of the fan design speed. The BFANS calculations were compared to experimental data in terms of total sound power spectra.

4.1 Acoustic Configurations

Figure 11 shows the fan configurations that were used during the acoustic tests. The rotor had a diameter of 18 in. and consisted of 20 blades. The stator configuration consisted of 60 radial vanes, 30 radial vanes, 15 radial vanes or no vanes. Reference 19 provides a more detailed description of the acoustic setup and farfield noise measurements. Appendix C provides a detailed description of the flow path, blade and vane geometry.

4.2 Flow-Field Measurement Configuration

Figure 12 shows the experimental setup used for hot-wire measurements. Station A was 4.3 in. downstream from the fan trailing edge tip, and Station B was approximately 1.2 in. upstream from the vane leading edge tip. Table 3 lists the HW data that were used in the present study. Reference 19 provides a detailed description of the HW data acquired.

The rig also had the capability to remove the endwall boundary layer at the fan tip. However, all BFaNS predictions in this report were performed with the full boundary layer (i.e., no suction). Also, all BFaNS predictions were done for the 60-vane configuration, with the low fan loading and small tip clearance.

TABLE 3.—HOT-WIRE DATA USED IN PRESENT STUDY, BOEING FAN

Percent design speed	Corrected fan speed (rpm)	HW data at station A	HW data at station B
55	9104	Yes	Yes
70	11586	Yes	Yes
88	14566	Yes	Yes

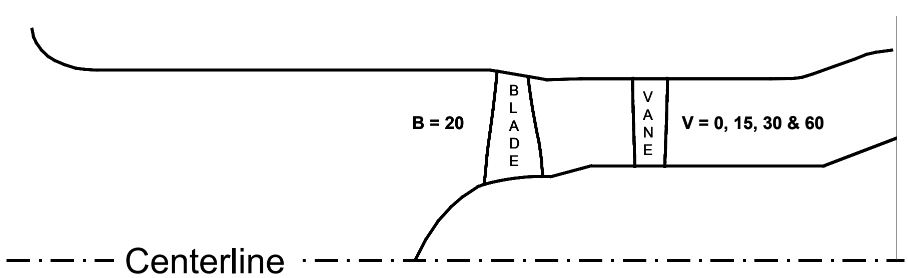


Figure 11.—Acoustic configuration, Boeing fan.

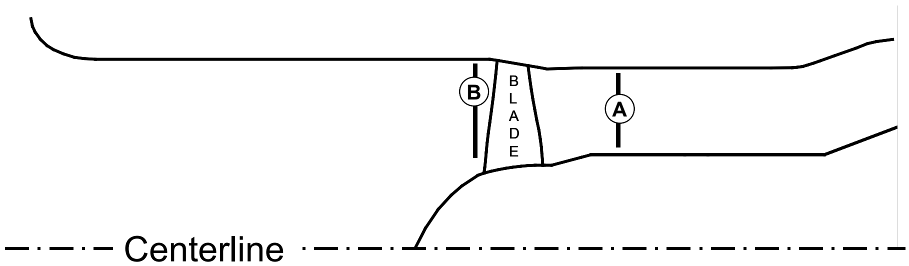


Figure 12.—Flow field measurement configuration, Boeing fan.

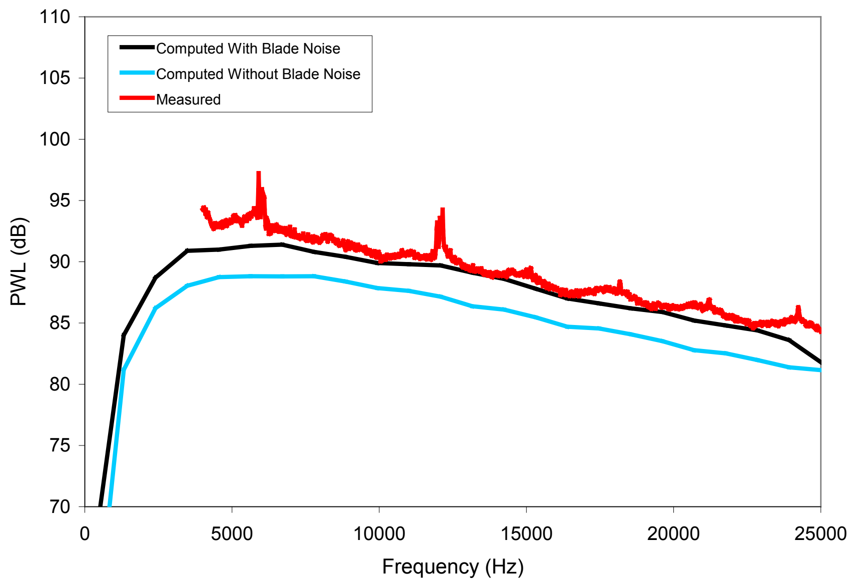


Figure 13.—Sound power spectrum, Boeing fan, 55 percent design speed (low loading, small clearance).

4.3 55 Percent Design Speed, Low Loading, Small Clearance

Figure 13 shows calculated and measured sound power spectra at 55 percent of design speed. The solid black line is the calculation with blade noise. The solid blue line is the calculation without blade noise. When blade noise is included, the calculated shape and level are in good agreement with the measured data. Without blade noise, the calculation is approximately 2 dB less than the data.

4.4 Effect of Fan Speed, Low Loading, Small Clearance

Figure 14 shows calculated and measured sound power spectra at 55, 70 and 88 percent of design speed. The calculations in Figure 14(a) include blade noise, while those in Figure 14(b) exclude blade noise. Note blade noise could not be computed at 88 percent of design speed because the tip Mach number is supersonic. The results show that BFaNS accurately predicted the shape and level of the spectra.

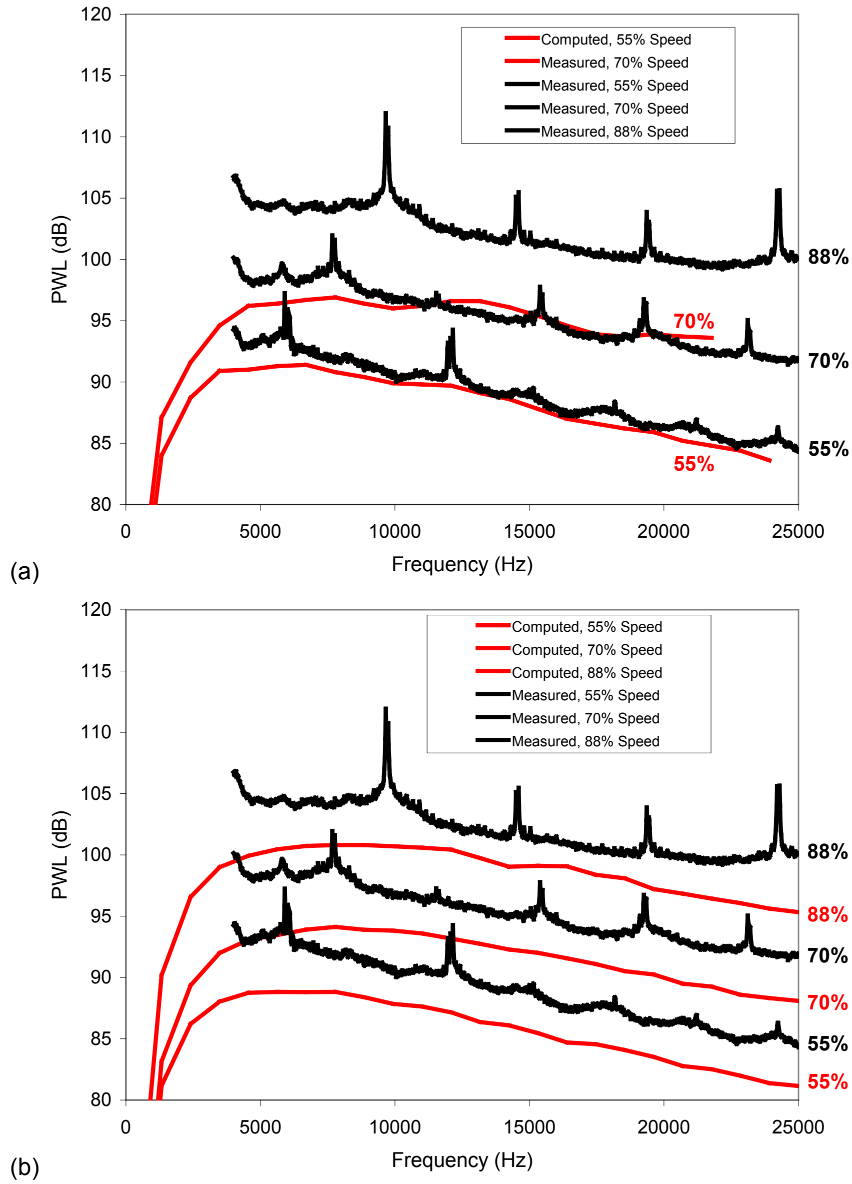


Figure 14.—Effect of fan speed, Boeing fan (low loading, small clearance): (a) Including blade noise; and (b) Excluding blade noise.

5.0 Concluding Remarks

Pratt & Whitney has developed a Broadband Fan Noise Prediction System (BFaNS) for turbofan engines. The noise prediction system consists of two computer programs: Setup_BFaNS and BFaNS. Setup_BFaNS converts user-specified geometry and flow-field information into a BFaNS input file. From this input file, BFaNS computes the inlet and aft broadband sound power spectra generated by the fan and FEGV. The output file from BFaNS contains the inlet, aft and total sound power spectra from each noise source.

This report documents the validation studies that were performed on three fan rigs that were tested during the NASA Advanced Subsonic Technology Program (AST). Volume 1 of this report series provides instructions for running Setup_BFaNS, and Volume 2 provides instructions for running BFaNS.

The validation studies have shown that BFaNS can accurately calculate the shape of the fan broadband noise spectra, and can calculate the spectrum level within a couple of decibels of measured data. BFaNS can also accurately calculate the effect of fan speed, vane count, and vane sweep. However, BFaNS cannot reliably calculate the contribution of blade noise relative to vane noise.

6.0 Recommendations

(1) Due to the empirical nature of the self-noise prediction, BFaNS cannot reliably predict the contribution of blade self noise relative to the turbulent inflow noise sources. The current self-noise prediction method should be replaced with a method that does not rely on empirical correlations, or one that is based on empirical correlations developed for cascade noise rather than isolated airfoil noise.

(2) BFaNS does not account for transmission loss across the rotor or stator. Hanson has recently developed this capability (Refs. 20 and 21), and it should be incorporated into BFaNS. This will improve the ability of BFaNS to predict the relative contribution of inlet and aft broadband noise.

(3) The cascade response routine in BFaNS is valid only for subsonic flows (i.e., when the incident Mach number is less than one). Therefore, BFaNS cannot calculate the noise produced by turbulence interacting with supersonic blade tips. This area deserves further attention because most commercial jet engines have supersonic blade tips at cutback and sideline power.

(4) The interaction between fan turbulence and the core stator should be added to BFaNS (this is a relatively easy enhancement).

(5) The modal content of the noise predicted by BFaNS should be used as input for duct propagation codes (CDUCT for example, see Ref. 22). This coupling between source prediction and duct propagation will enhance the capability of the aerospace industry to optimize liner designs and reduce noise.

(6) Thus far, BFaNS has been validated on a partial set of data that was acquired during the AST program. BFaNS should be thoroughly validated on all the rig data, including the Allison 22-in. fan rig. BFaNS should also be validated on full-scale engine data, which would require turbulence measurements on a full-scale engine.

Appendix A.—Pratt & Whitney/NASA Fan Rig Information

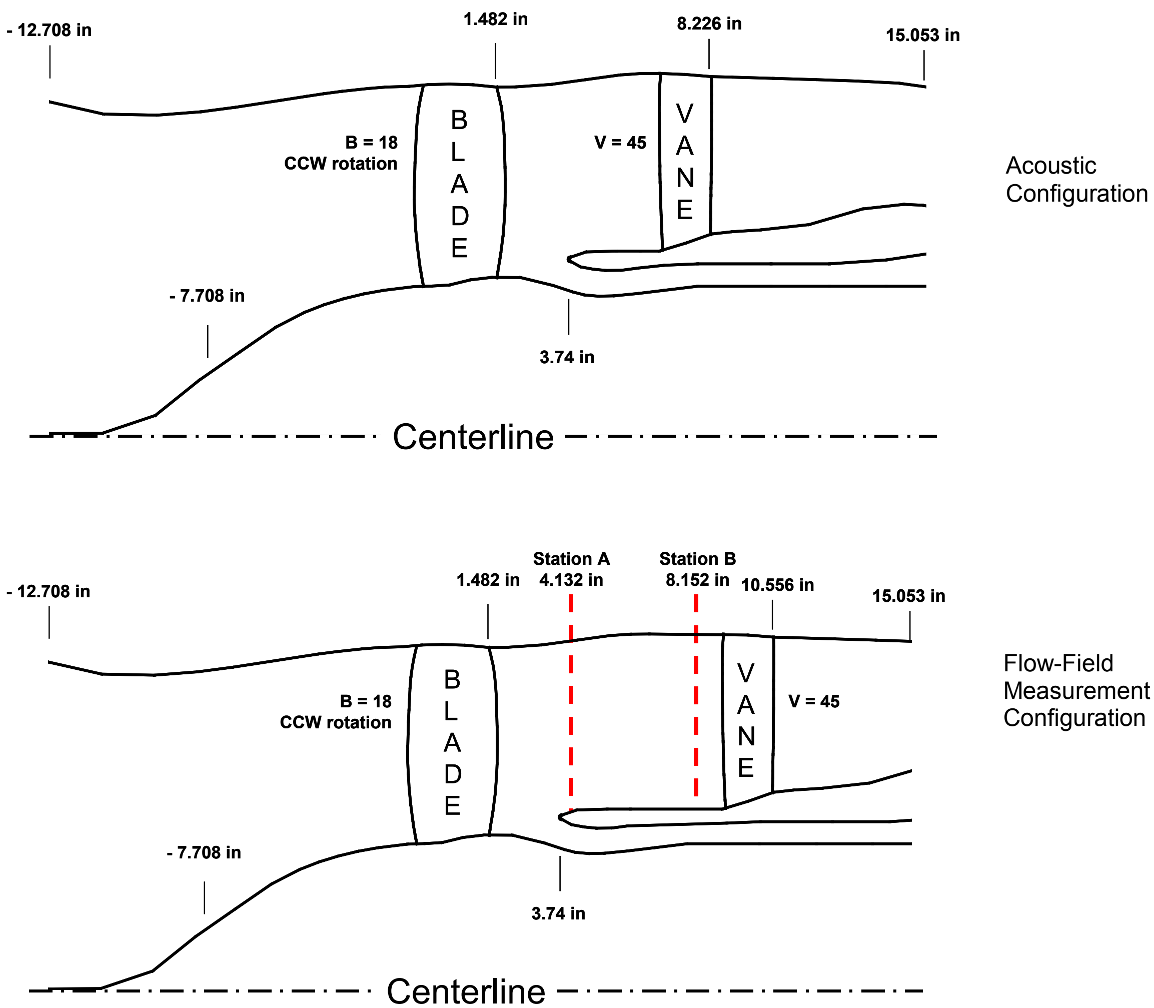


Figure A.1—Fan no. 1 rig schematics.

Note: The nose cone shown above does not represent the actual noise-cone geometry used during the test. It is merely an approximation to facilitate flow-field calculations that were performed on the Fan #1 configuration.

A.1 Fan No. 1, Flow-Path Geometry File

```
Flowpath: I.D. wall
35
Axial
    -23.1900    -19.1000    -16.8500    -14.6500    -12.5600    -10.8900
     -9.2300     -7.8640     -6.5970     -5.4480     -4.5480     -3.9350
     -3.3150     -2.6900     -2.0600     -1.1100     -0.5550      0.0000
      0.6650      1.3300      2.2300      3.2400
      3.8900      4.2420      4.6730      5.1700      5.9100      6.7400
      7.8000     10.1000     11.9300     13.7100     15.0900     17.1400
     19.6200
Radius
```

```
      0.0600      0.0600      0.0600      0.0600      0.0600      0.0750
      0.6350      1.7335      2.6200      3.4120      3.8770      4.1175
      4.3110      4.4620      4.5740      4.6900      4.7090      4.7405
      4.9020      4.9840      4.9750      4.7300
      4.5150      4.4300      4.3870      4.4000      4.4750      4.5750
      4.7000      4.7000      4.7000      4.7000      4.7000      4.7200
      5.2350
Primary Splitter: Duct I.D. wall
30
Axial
      3.7400      3.7407      3.7418      3.7435      3.7452      3.7470
      3.7505      3.7540      3.7575      3.7610      3.7680      3.7750
      3.7820      3.7890      3.7960      3.8030      3.8100
      4.2900      5.2500      5.9900      6.5920      7.4220      8.2260
      8.8780      9.7700     11.2900     12.9700     14.2700     14.8500
     16.5300
Radius
      5.5500      5.5599      5.5656      5.5719      5.5766      5.5805
      5.5869      5.5920      5.5963      5.6000      5.6060      5.6106
      5.6142      5.6168      5.6186      5.6196      5.6200
      5.7850      5.8100      5.8100      5.8100      6.0600      6.3500
      6.4200      6.4750      6.6450      7.1350      7.2850      7.2550
      6.9650
Primary Splitter: Core O.D. wall
30
Axial
      3.7400      3.7407      3.7418      3.7435      3.7452      3.7470
      3.7505      3.7540      3.7575      3.7610      3.7680      3.7750
      3.7820      3.7890      3.7960      3.8030      3.8100
      4.1200      4.5130      4.9030      5.4100      5.9100      6.7400
      7.8000     10.1000     11.9300     13.7100     15.0900     17.1400
     19.6200
Radius
      5.5500      5.5401      5.5344      5.5281      5.5234      5.5195
      5.5131      5.5080      5.5037      5.5000      5.4940      5.4894
      5.4858      5.4832      5.4814      5.4804      5.4800
      5.3100      5.2420      5.2020      5.2050      5.2750      5.3640
      5.4100      5.4100      5.4100      5.5300      5.7350      6.1000
      6.5850
Flowpath: O.D. wall
35
Axial
    -23.1900    -19.1000    -16.8500    -14.6500    -12.5600    -10.8540
     -9.1758     -7.7958     -6.6918     -5.3119     -4.4839     -3.9320
     -3.3800     -2.5520     -2.0000     -1.2796     -0.6530      0.0000
      0.7410      1.4820      2.0700      3.1900
      4.2900      5.3400      5.9900      6.5920      7.4090      8.2260
      8.8700     10.1800     11.4900     12.8000     14.1100     15.0000
     16.5300
Radius
     11.1200     11.1200     11.1200     10.9050     10.5100     10.1270
     10.0915     10.2000     10.3425     10.5575     10.6885     10.7700
     10.8435     10.9330     10.9760     11.0000     11.0550     11.0735
     11.0490     10.9760     10.9850     11.0600
     11.2100     11.3600     11.4000     11.4100     11.3750     11.3100
     11.2900     11.2500     11.2100     11.1650     11.1000     10.9750
     10.7300
```

A.2 Fan No. 1, Blade Geometry File

```
LOW NOISE FAN 806 B AERO TD47877-9 SLTO
   20
'XLE             '
 4.65548      4.80239      4.94556      5.08495      5.22093      5.35348
 5.90934      6.41638      6.88740      7.32601      7.74196      8.13807
 8.51869      8.88521      9.23982      9.58395      9.91842      10.2435
 10.5587      10.8633
'YLE             '
-.567895     -.588340     -.609174     -.629111     -.648962     -.667595
-.744498     -.824584     -.904788     -.992043     -1.08189     -1.16632
```

```
-1.24253     -1.31212     -1.37652     -1.43886     -1.50221     -1.57272
-1.65190     -1.72870
'ZLE          '
-1.00811     -1.03756     -1.06347     -1.08875     -1.11289     -1.13349
-1.20593     -1.25193     -1.28397     -1.30400     -1.29983     -1.28975
-1.27619     -1.26075     -1.24393     -1.22449     -1.19780     -1.15417
-1.09281     -1.02071
'BETA1*ML     '
 55.7458      54.9105      54.0276      53.2297      52.4571      51.6819
 48.7347      46.6936      44.6492      42.2231      39.6174      37.5233
 35.8931      34.5615      33.3949      32.2920      31.1840      29.9504
 28.6866      27.4006
'XTE          '
 4.93962      5.10930      5.26980      5.42266      5.56906      5.70931
 6.27890      6.78156      7.23521      7.65333      8.04079      8.40556
 8.75182      9.08183      9.39724      9.69970      9.99141      10.2808
 10.5657      10.8751
'YTE          '
0.524705     0.517738     0.514805     0.513000     0.512786     0.512125
0.513708     0.532117     0.572642     0.625699     0.710444     0.804671
0.894696     0.979065      1.05923      1.13705      1.21706      1.30696
 1.40889      1.51529
'ZTE          '
 1.29429      1.32014      1.34422      1.36786      1.39068      1.41338
 1.48889      1.52820      1.54646      1.55607      1.55606      1.54638
 1.53929      1.53107      1.51853      1.50025      1.47267      1.42852
 1.36479      1.28487
'BETA2*       '
 76.1635      77.4035      78.2908      79.0146      79.5876      80.0921
 82.0861      83.9269      84.3108      82.0091      78.5042      75.2138
 72.2325      69.4598      66.8028      64.1682      61.4027      58.3470
 54.9446      51.2012
```

A.3 Fan No. 1, Vane Geometry File

```
LOW NOISE FEGV X15 25 sl's slto
   20
'XLE          '
 5.81543      6.07863      6.35643      6.59566      6.90891      7.18609
 7.43791      7.67066      7.95978      8.23011      8.48556      8.84815
 9.18955      9.51486      9.82664      10.1281      10.4232      10.7192
 11.0326      11.4030
'YLE          '
-.449733     -.430289     -.411172     -.395951     -.377949     -.364261
-.353612     -.345217     -.336145     -.328454     -.321500     -.311809
-.303671     -.297059     -.291824     -.288351     -.287275     -.297467
-.335125     -.415682
'ZLE          '
-.713627     -.728927     -.742346     -.752635     -.764726     -.774127
-.781648     -.787710     -.794249     -.799586     -.804088     -.809806
-.814288     -.817782     -.820461     -.822273     -.823108     -.820298
-.807738     -.773823
'BETA1*ML     '
 37.3937      39.0014      40.5328      41.7413      43.1730      44.2960
 45.2044      45.9543      46.7966      47.5311      48.1919      49.0922
 49.8502      50.4856      51.0276      51.4772      51.7887      51.2722
 48.8049      43.2694
'XTE          '
 6.32387      6.55653      6.80855      7.02577      7.30814      7.55533
 7.77806      7.98297      8.23775      8.47732      8.70524      9.03119
 9.33987      9.63470      9.91772      10.1917      10.4606      10.7302
 11.0101      11.3128
'YTE          '
0.123309     0.112095     0.101454     0.931932E-01 0.837858E-01 0.770896E-01
0.723298E-01 0.691759E-01 0.659385E-01 0.628574E-01 0.598547E-01 0.551050E-01
0.510384E-01 0.476922E-01 0.449980E-01 0.434292E-01 0.431074E-01 0.477307E-01
0.657158E-01 0.105735
'ZTE          '
0.775949     0.782104     0.786912     0.790609     0.795179     0.799012
0.802266     0.804980     0.807934     0.810288     0.812156     0.814328
```

```
0.815905     0.817067     0.817894     0.818404     0.818659     0.818807
0.818535     0.815486
'BETA2*          '
 96.9231      96.6664      96.3713      96.1203      95.7892      95.5016
 95.2361      94.9556      94.6544      94.4819      94.3689      94.3057
 94.2763      94.2799      94.3256      94.3937      94.5246      94.9275
 95.8411      97.4711
```

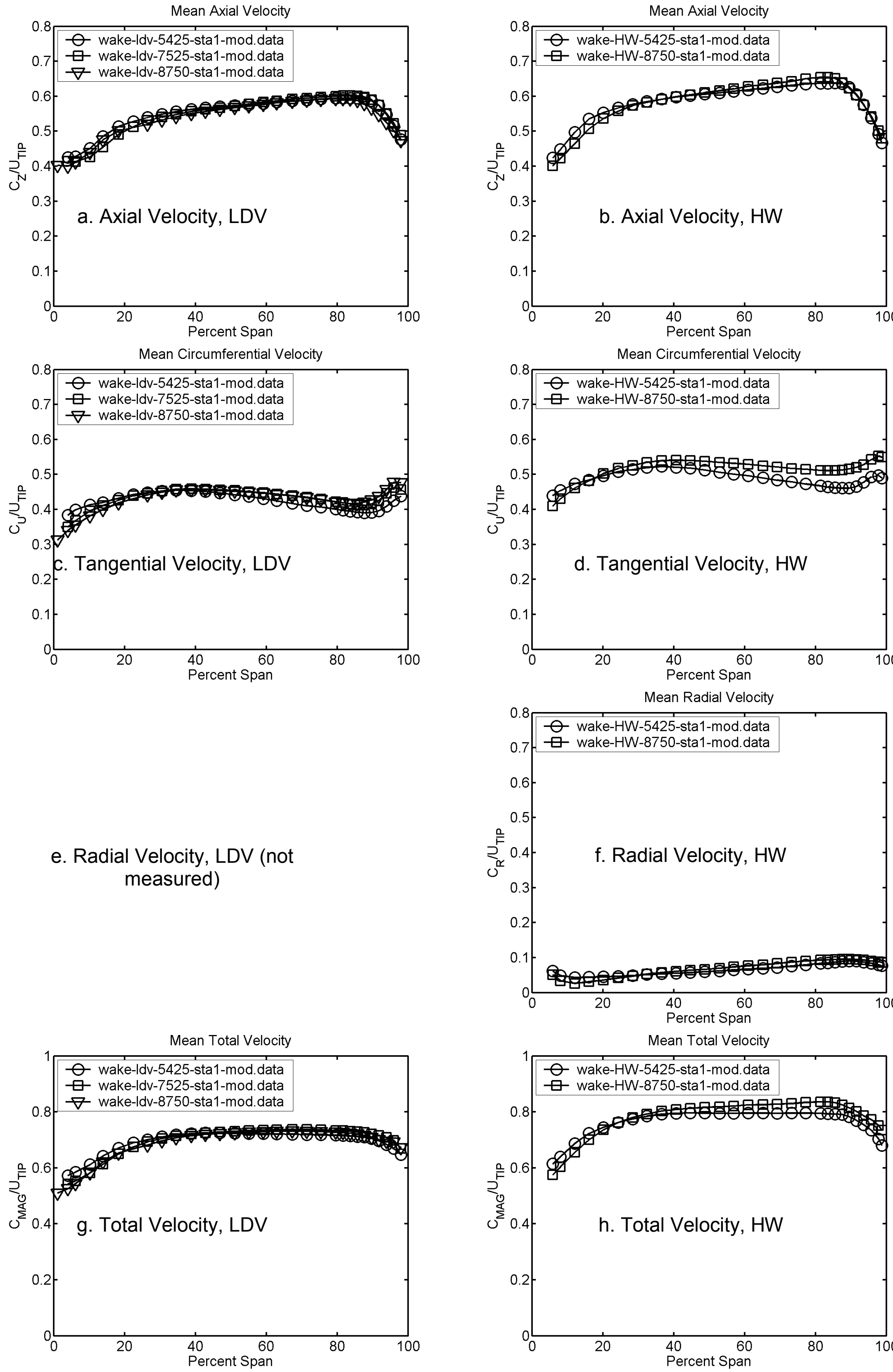


Figure A.2.—Fan no. 1, average velocity, station A.

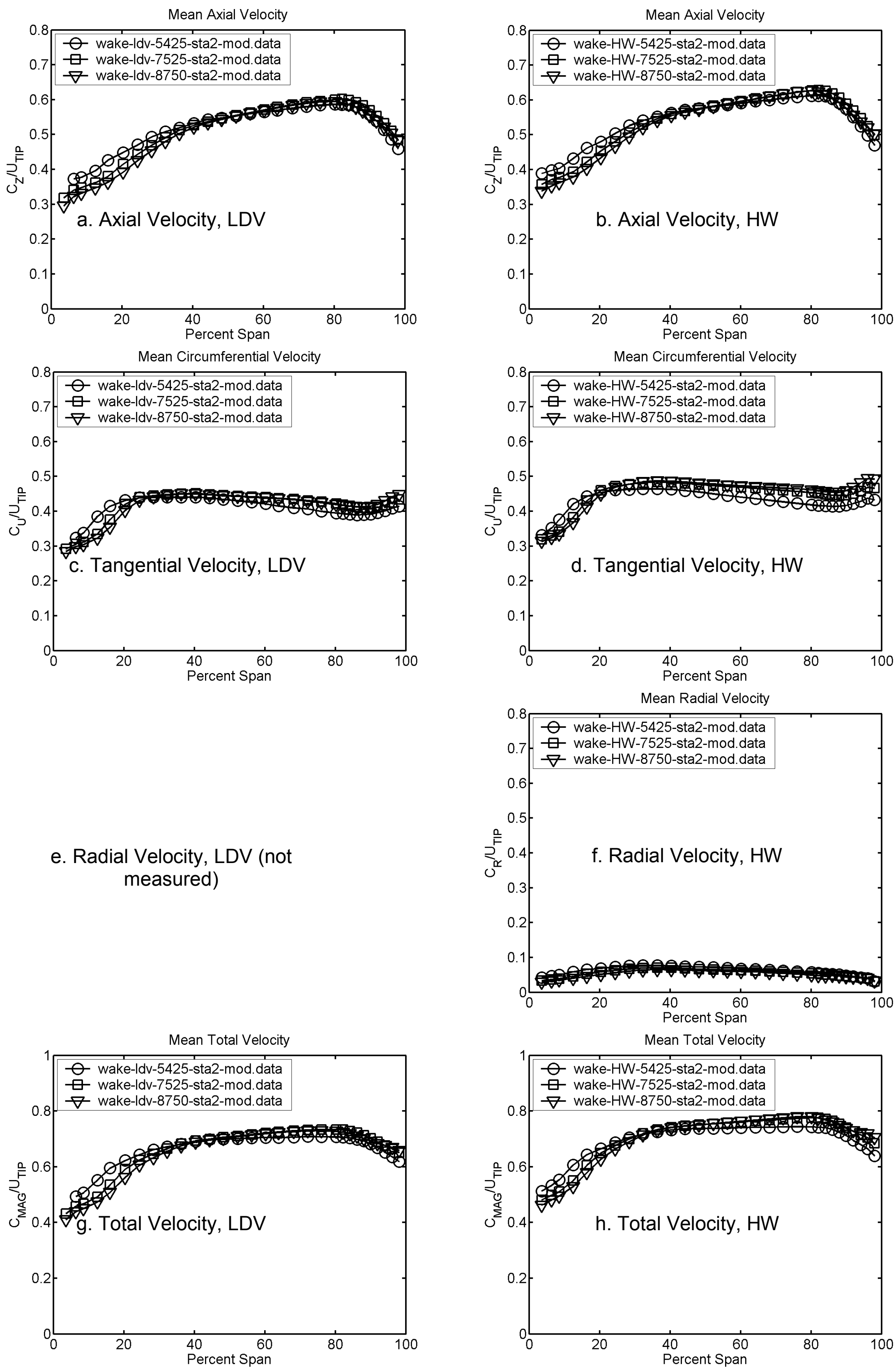


Figure A.3.—Fan no. 1, average velocity, station B.

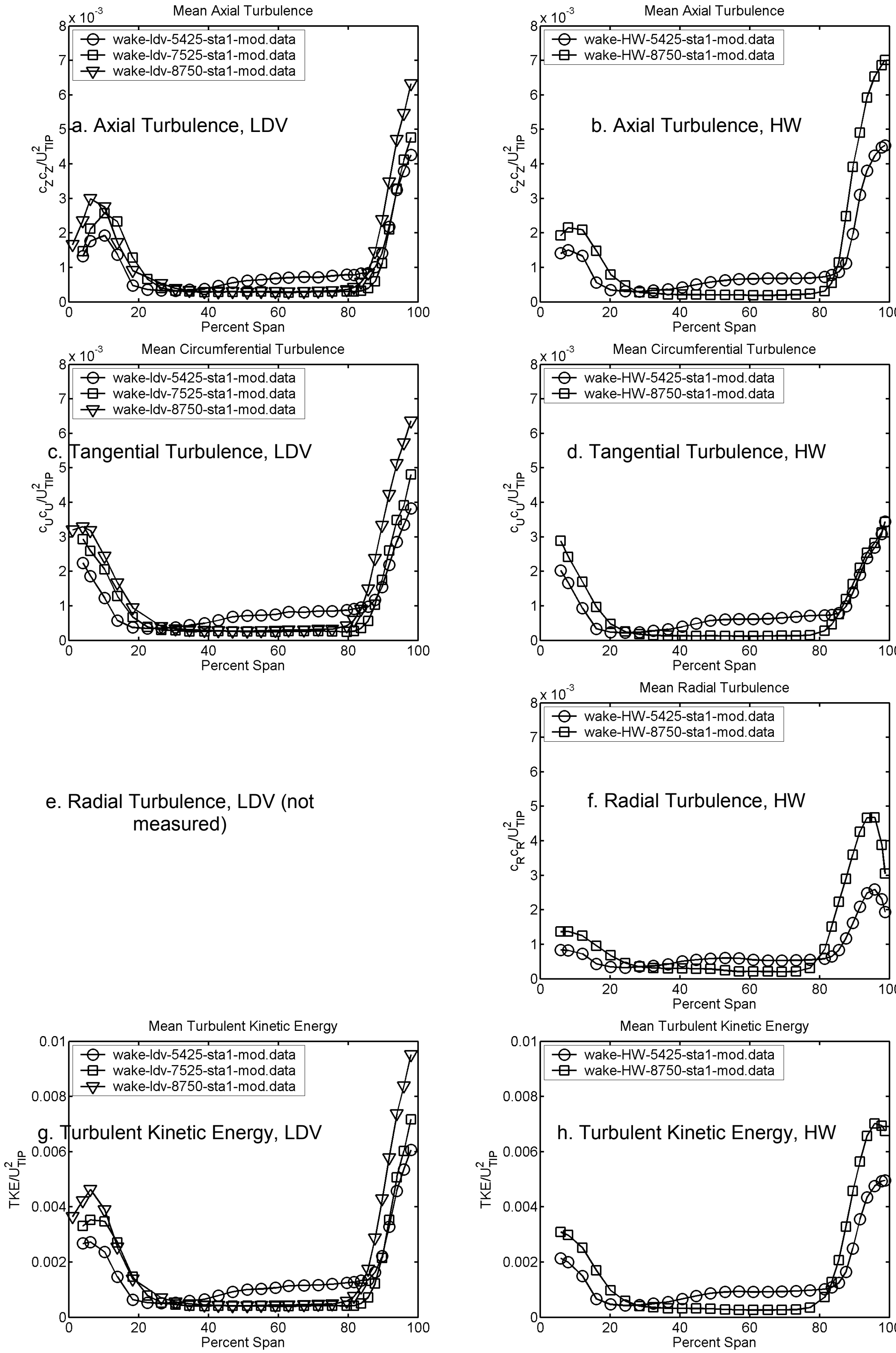


Figure A.4.—Fan no. 1, average turbulence intensity, station A.

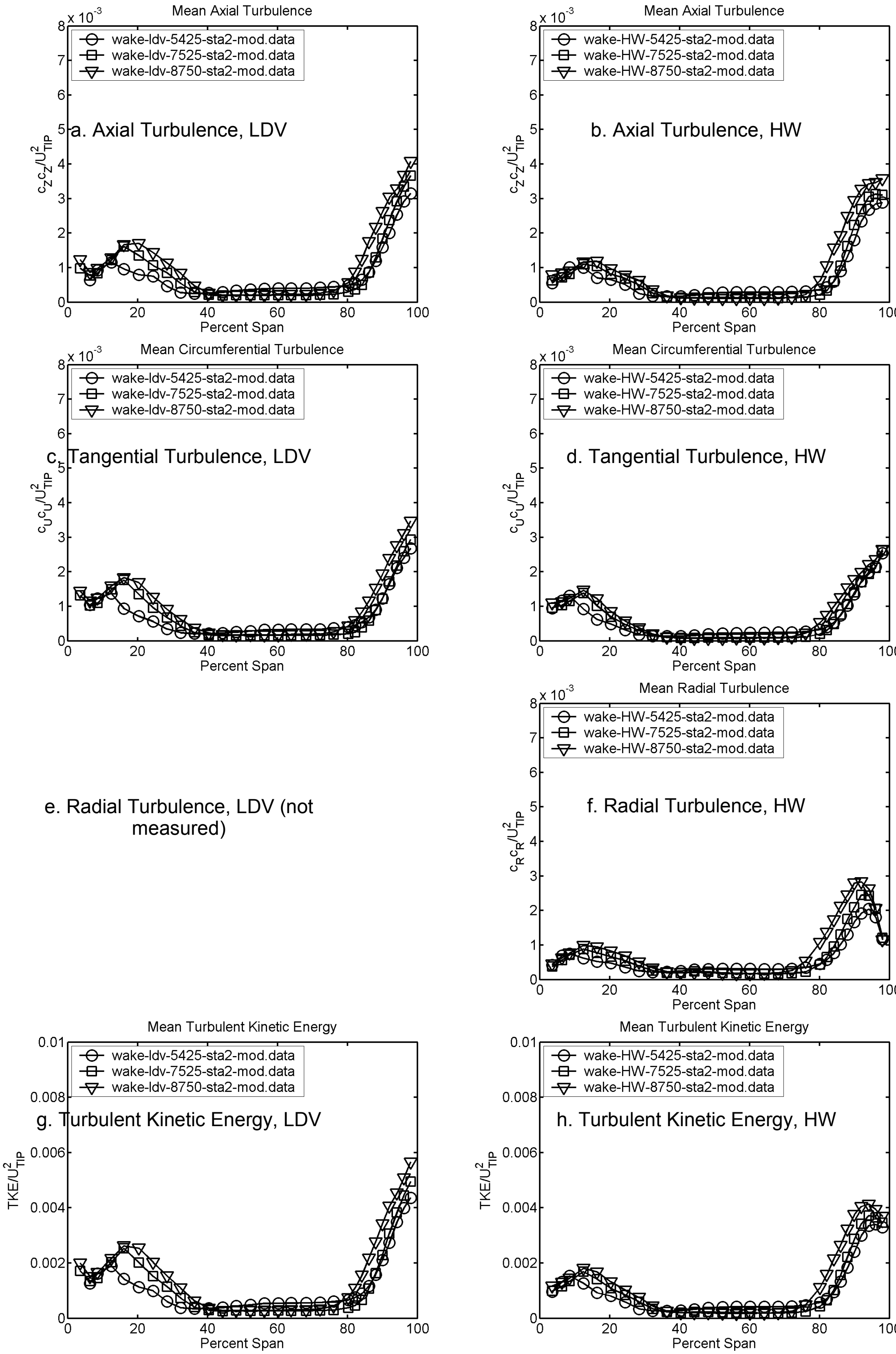


Figure A.5.—Fan no. 1, average turbulence intensity, station B.

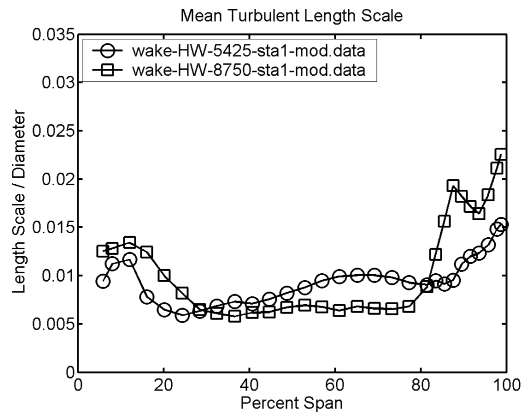


Figure A.6.—Fan no. 1, average turbulence scale, station A.

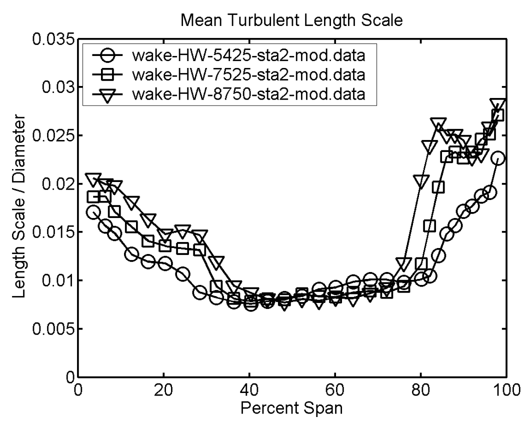


Figure A.7.—Fan no. 1, average turbulence scale, station B.

Appendix B.—General Electric/NASA Fan Rig Information

Note: The M5 geometry was not available; therefore, noise predictions for the M5 fan were not performed

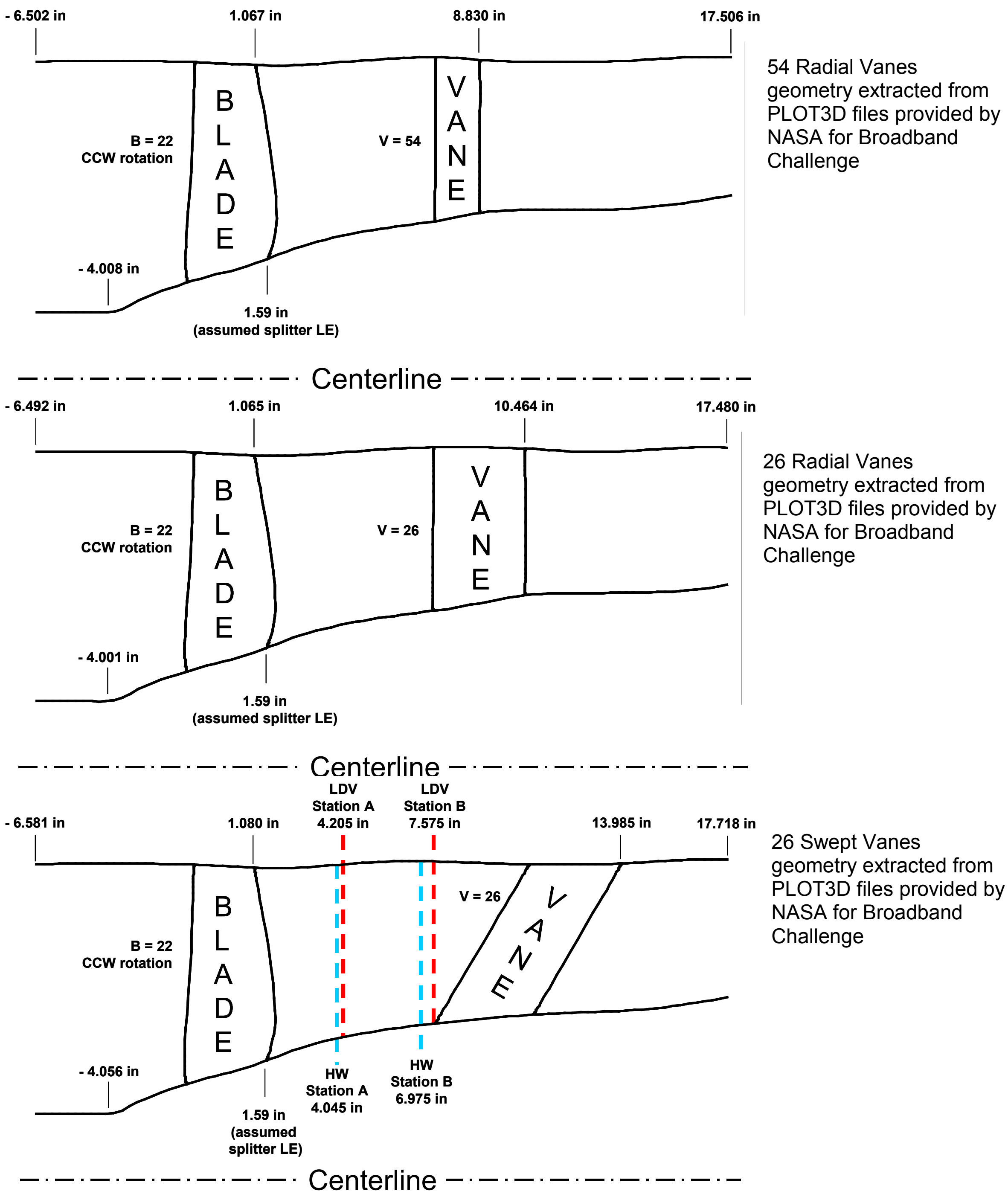


Figure B.1.—R4 fan rig schematics.

Note: The nose cone shown above does not represent the actual noise-cone geometry used during the test. It is merely an approximation to facilitate flow-field calculations that were performed on the R4 fan configuration.

B.1 R4 Fan, 54 Radial Vanes, Flow-Path Geometry File

```
Flowpath:  Inside Diameter Wall - HUB
   90
 Axial
   -6.502327     -6.232568     -5.962808     -5.693049     -5.423289
   -5.153530     -4.883770     -4.614011     -4.344251     -4.074492
   -3.804733     -3.534973     -3.265214     -2.995454     -2.725695
   -2.455935     -2.186176     -1.916416     -1.646657     -1.376897
   -1.107138     -0.837379     -0.567619     -0.297860     -0.028100
    0.241659      0.511419      0.781178      1.050938      1.320697
    1.590456      1.860216      2.129975      2.399735      2.669494
    2.939254      3.209013      3.478773      3.748532      4.018291
    4.288051      4.557810      4.827570      5.097329      5.367089
    5.636848      5.906608      6.176367      6.446126      6.715886
    6.985645      7.255405      7.525164      7.794924      8.064683
    8.334443      8.604202      8.873961      9.143721      9.413480
    9.683240      9.952999     10.222759     10.492518     10.762278
   11.032037     11.301796     11.571556     11.841315     12.111075
   12.380834     12.650594     12.920353     13.190113     13.459872
   13.729631     13.999391     14.269150     14.538910     14.808669
   15.078429     15.348188     15.617948     15.887707     16.157467
   16.427226     16.696985     16.966745     17.236504     17.506264
 Radius
    2.250805      2.250757      2.250756      2.250848      2.250945
    2.250903      2.250703      2.251318      2.250003      2.268878
    2.297416      2.373692      2.525183      2.674208      2.791127
    2.900357      3.002891      3.099274      3.189671      3.276292
    3.358367      3.435867      3.509917      3.581078      3.650682
    3.720369      3.794309      3.878063      3.969007      4.067281
    4.170762      4.275789      4.379734      4.479830      4.572974
    4.656779      4.731721      4.799961      4.862569      4.921029
    4.976265      5.029055      5.079441      5.127756      5.173022
    5.214311      5.251548      5.287234      5.322437      5.356940
    5.391048      5.429903      5.478404      5.534245      5.592687
    5.649140      5.699345      5.740850      5.772924      5.795676
    5.810992      5.821017      5.827340      5.831110      5.833467
    5.835088      5.836256      5.836969      5.836978      5.836439
    5.836241      5.837039      5.839078      5.843604      5.850944
    5.859892      5.875535      5.892634      5.916299      5.941113
    5.971357      6.001601      6.037731      6.073982      6.113309
    6.155001      6.196693      6.242894      6.289515      6.336137

 Primary Splitter:  Inside Diameter Wall - UPPER
   60
 Axial
    1.590456      1.860216      2.129975      2.399735      2.669494
    2.939254      3.209013      3.478773      3.748532      4.018291
    4.288051      4.557810      4.827570      5.097329      5.367089
    5.636848      5.906608      6.176367      6.446126      6.715886
    6.985645      7.255405      7.525164      7.794924      8.064683
    8.334443      8.604202      8.873961      9.143721      9.413480
    9.683240      9.952999     10.222759     10.492518     10.762278
   11.032037     11.301796     11.571556     11.841315     12.111075
   12.380834     12.650594     12.920353     13.190113     13.459872
   13.729631     13.999391     14.269150     14.538910     14.808669
   15.078429     15.348188     15.617948     15.887707     16.157467
   16.427226     16.696985     16.966745     17.236504     17.506264
 Radius
    4.170762      4.275788      4.379734      4.479830      4.572974
    4.656778      4.731722      4.799960      4.862567      4.921028
    4.976264      5.029056      5.079442      5.127756      5.173022
    5.214311      5.251549      5.287233      5.322438      5.356940
    5.391048      5.429903      5.478404      5.534245      5.592687
    5.649140      5.699345      5.740850      5.772924      5.795675
    5.810993      5.821017      5.827340      5.831110      5.833467
    5.835088      5.836256      5.836969      5.836978      5.836440
    5.836242      5.837039      5.839078      5.843604      5.850944
    5.859892      5.875535      5.892634      5.916299      5.941114
    5.971357      6.001601      6.037731      6.073982      6.113308
    6.155001      6.196693      6.242894      6.289515      6.336136
```

```
Primary Splitter:  Outside Diameter Wall - LOWER
   60
 Axial
    1.590456      1.860216      2.129975      2.399735      2.669494
    2.939254      3.209013      3.478773      3.748532      4.018291
    4.288051      4.557810      4.827570      5.097329      5.367089
    5.636848      5.906608      6.176367      6.446126      6.715886
    6.985645      7.255405      7.525164      7.794924      8.064683
    8.334443      8.604202      8.873961      9.143721      9.413480
    9.683240      9.952999     10.222759     10.492518     10.762278
   11.032037     11.301796     11.571556     11.841315     12.111075
   12.380834     12.650594     12.920353     13.190113     13.459872
   13.729631     13.999391     14.269150     14.538910     14.808669
   15.078429     15.348188     15.617948     15.887707     16.157467
   16.427226     16.696985     16.966745     17.236504     17.506264
 Radius
    4.170762      4.275788      4.379734      4.479830      4.572974
    4.656778      4.731722      4.799960      4.862567      4.921028
    4.976264      5.029056      5.079442      5.127756      5.173022
    5.214311      5.251549      5.287233      5.322438      5.356940
    5.391048      5.429903      5.478404      5.534245      5.592687
    5.649140      5.699345      5.740850      5.772924      5.795675
    5.810993      5.821017      5.827340      5.831110      5.833467
    5.835088      5.836256      5.836969      5.836978      5.836440
    5.836242      5.837039      5.839078      5.843604      5.850944
    5.859892      5.875535      5.892634      5.916299      5.941114
    5.971357      6.001601      6.037731      6.073982      6.113308
    6.155001      6.196693      6.242894      6.289515      6.336136

 Flowpath:  Outside Diameter Wall - TIP
   90
 Axial
   -6.502327     -6.232568     -5.962808     -5.693049     -5.423289
   -5.153530     -4.883770     -4.614011     -4.344251     -4.074492
   -3.804733     -3.534973     -3.265214     -2.995454     -2.725695
   -2.455935     -2.186176     -1.916416     -1.646657     -1.376897
   -1.107138     -0.837379     -0.567619     -0.297860     -0.028100
    0.241659      0.511419      0.781178      1.050938      1.320697
    1.590456      1.860216      2.129975      2.399735      2.669494
    2.939254      3.209013      3.478773      3.748532      4.018291
    4.288051      4.557810      4.827570      5.097329      5.367089
    5.636848      5.906608      6.176367      6.446126      6.715886
    6.985645      7.255405      7.525164      7.794924      8.064683
    8.334443      8.604202      8.873961      9.143721      9.413480
    9.683240      9.952999     10.222759     10.492518     10.762278
   11.032037     11.301796     11.571556     11.841315     12.111075
   12.380834     12.650594     12.920353     13.190113     13.459872
   13.729631     13.999391     14.269150     14.538910     14.808669
   15.078429     15.348188     15.617948     15.887707     16.157467
   16.427226     16.696985     16.966745     17.236504     17.506264
 Radius
   11.010941     11.012493     11.013998     11.015268     11.016401
   11.017396     11.018124     11.018691     11.019068     11.019232
   11.019168     11.018869     11.018327     11.017558     11.016528
   11.015241     11.013677     11.011839     11.011221     11.006656
   10.995469     10.981015     10.966768     10.953494     10.940141
   10.926359     10.912204     10.898097     10.884698     10.873096
   10.865967     10.865466     10.870844     10.879611     10.891271
   10.905508     10.922375     10.941645     10.962651     10.984550
   11.006749     11.028477     11.048728     11.067650     11.085357
   11.101904     11.117003     11.130196     11.141621     11.150951
   11.157653     11.160125     11.156557     11.145514     11.127017
   11.104327     11.080913     11.059781     11.042190     11.028078
   11.017560     11.010750     11.006802     11.004715     11.003883
```

```
   11.003863     11.003966     11.003947     11.003903     11.003971
   11.003982     11.003810     11.003820     11.006583     11.013209
   11.022273     11.036808     11.051996     11.069672     11.087250
   11.104318     11.121385     11.134995     11.148494     11.158052
   11.164576     11.171100     11.168430     11.164928     11.161425
```

B.1.1 R4 Fan, 54 Radial Vanes, Blade Geometry File

```
NASA SOURCE DIAGNOSTICS FAN ROTOR AIRFOIL DATA
   51
 XLE
   -3.300717     -3.303915     -3.308069     -3.313466     -3.320478
   -3.329237     -3.340175     -3.353832     -3.370878     -3.392150
   -3.418686     -3.451780     -3.493053     -3.544538     -3.608829
   -3.689264     -3.790090     -3.916614     -4.075167     -4.273249
   -4.520267     -4.828773     -5.215665     -5.700811     -6.305202
   -7.061386     -7.823350     -8.427943     -8.918634     -9.317897
   -9.638566     -9.894466    -10.098216    -10.260604    -10.390247
  -10.493849    -10.576728    -10.643064    -10.696157    -10.738645
  -10.772639    -10.799839    -10.821598    -10.839005    -10.852930
  -10.864068    -10.872978    -10.880105    -10.885588    -10.889806
  -10.893050
 YLE
    0.056513      0.058546      0.061189      0.064622      0.069084
    0.074656      0.081611      0.090283      0.101076      0.114469
    0.131012      0.151285      0.175824      0.204982      0.238555
    0.275329      0.313901      0.353320      0.395976      0.448298
    0.516396      0.600231      0.691755      0.792850      0.932052
    1.099041      1.227651      1.360980      1.423135      1.429222
    1.423645      1.421848      1.426293      1.433713      1.441308
    1.448014      1.453255      1.457092      1.459912      1.462011
    1.463594      1.464802      1.465734      1.466459      1.467026
    1.467472      1.467826      1.468104      1.468316      1.468480
    1.468602
 ZLE
   -1.297397     -1.297990     -1.298759     -1.299756     -1.301048
   -1.302654     -1.304649     -1.307122     -1.310177     -1.313935
   -1.318526     -1.324082     -1.330689     -1.338260     -1.346318
   -1.353738     -1.359192     -1.361348     -1.360299     -1.357423
   -1.351905     -1.338306     -1.312679     -1.274927     -1.226397
   -1.165348     -1.119212     -1.100427     -1.086893     -1.073364
   -1.064533     -1.060213     -1.057601     -1.055210     -1.052501
   -1.049508     -1.046523     -1.043761     -1.041353     -1.039327
   -1.037654     -1.036288     -1.035179     -1.034283     -1.033560
   -1.032978     -1.032511     -1.032136     -1.031847     -1.031624
   -1.031453
 BETAT1
   66.841801     66.815885     66.783103     66.742593     66.683989
   66.614494     66.518115     66.399710     66.240933     66.033458
   65.750624     65.367511     64.835773     64.115349     63.168008
   61.994470     60.685418     59.429298     58.195041     56.664610
   54.802715     53.044276     51.019784     48.935041     46.509141
   43.978135     41.697607     39.574998     38.087785     36.851772
   35.808748     35.100205     34.436097     33.761993     33.149026
   32.648950     32.246985     31.915624     31.643311     31.425093
   31.245763     31.101723     30.986595     30.895777     30.819186
   30.759661     30.714022     30.676131     30.646688     30.624129
   30.608167
 XTE
   -4.088949     -4.092535     -4.097195     -4.103248     -4.111110
   -4.120854     -4.132927     -4.147878     -4.166385     -4.189279
   -4.217576     -4.252514     -4.295610     -4.348718     -4.414104
   -4.494511     -4.593260     -4.714419     -4.862988     -5.045069
   -5.268126     -5.541716     -5.878458     -6.292905     -6.801577
   -7.431083     -8.067842     -8.579360     -8.995760     -9.339889
   -9.620321     -9.846050    -10.027071    -10.172226    -10.288950
  -10.382961    -10.458827    -10.520140    -10.569674    -10.609668
  -10.641939    -10.667974    -10.688969    -10.705896    -10.719543
  -10.730546    -10.739413    -10.746562    -10.752061    -10.756291
  -10.759545
 YTE
```

```
    0.595555      0.593313      0.590397      0.586604      0.581671
    0.575546      0.567943      0.558513      0.546824      0.532360
    0.514516      0.492602      0.465780      0.433002      0.392969
    0.344221      0.285327      0.214571      0.129390      0.026424
   -0.097081     -0.237919     -0.392177     -0.576410     -0.812905
   -1.075679     -1.269325     -1.430582     -1.533526     -1.565878
   -1.572818     -1.579427     -1.590009     -1.603047     -1.615155
   -1.625258     -1.632740     -1.637674     -1.640837     -1.642914
   -1.644310     -1.645274     -1.645954     -1.646446     -1.646806
   -1.647074     -1.647280     -1.647433     -1.647550     -1.647635
   -1.647700
```

```
 ZTE
    1.490532      1.491784      1.493412      1.495524      1.498265
    1.501657      1.505851      1.511032      1.517420      1.525280
    1.534918      1.546681      1.560933      1.578008      1.598115
    1.621252      1.647092      1.675143      1.705382      1.738630
    1.773224      1.795254      1.785352      1.761071      1.718796
    1.631256      1.531697      1.440159      1.362147      1.302295
    1.252064      1.208955      1.174382      1.147466      1.126418
    1.109854      1.096681      1.086109      1.077594      1.070730
    1.065192      1.060726      1.057124      1.054220      1.051879
    1.049991      1.048470      1.047244      1.046300      1.045575
    1.045016
 BETAT2
  123.481562    123.359068    123.200406    122.994211    122.723927
  122.390499    121.977237    121.463885    120.829013    120.048534
  119.084911    117.907573    116.482608    114.764199    112.735775
  110.376564    107.716961    104.740661    101.130447     96.493614
   90.782852     84.861986     79.986424     74.797613     68.264310
   59.838997     53.438499     49.173076     45.258556     43.025379
   42.047168     41.267618     40.301256     39.256656     38.427494
   37.915711     37.615648     37.431940     37.300851     37.201613
   37.121749     37.054726     37.000575     36.955608     36.922670
   36.894472     36.866245     36.849647     36.828629     36.820108
   36.812149
```

B.1.2 R4 Fan, 54 Radial Vanes, Vane Geometry File

```
NASA SOURCE DIAGNOSTICS VANE STATOR AIRFOIL DATA
   51
 XLE
   -5.416727     -5.419984     -5.424215     -5.429717     -5.436869
   -5.445656     -5.456452     -5.469716     -5.486012     -5.506033
   -5.530631     -5.560848     -5.597970     -5.643573     -5.699591
   -5.768402     -5.852918     -5.956717     -6.084190     -6.240739
   -6.433002     -6.669145     -6.959180     -7.315404     -7.752908
   -8.290226     -8.827341     -9.264373     -9.619956     -9.909304
  -10.144755    -10.336369    -10.492330    -10.619282    -10.722619
  -10.806724    -10.875172    -10.930878    -10.976212    -11.013106
  -11.043136    -11.067576    -11.087468    -11.103658    -11.116835
  -11.127559    -11.136287    -11.143391    -11.148856    -11.153060
  -11.156293
 YLE
   -0.406363     -0.406194     -0.405973     -0.405686     -0.405312
   -0.404852     -0.404287     -0.403591     -0.402734     -0.401682
   -0.400392     -0.398819     -0.396905     -0.394579     -0.391767
   -0.388400     -0.384440     -0.379891     -0.374796     -0.369099
   -0.362613     -0.354976     -0.345888     -0.335125     -0.322678
   -0.308797     -0.296720     -0.288643     -0.284890     -0.283530
   -0.283985     -0.285139     -0.285764     -0.285726     -0.285371
   -0.285092     -0.285040     -0.285216     -0.285526     -0.285869
   -0.286190     -0.286472     -0.286714     -0.286918     -0.287089
   -0.287229     -0.287347     -0.287443     -0.287516     -0.287574
   -0.287618
 ZLE
    7.267998      7.268016      7.268040      7.268072      7.268112
    7.268163      7.268225      7.268301      7.268394      7.268508
```

```
   7.268649     7.268822     7.269035     7.269298     7.269619
   7.270013     7.270496     7.271083     7.271793     7.272658
   7.273715     7.275023     7.276612     7.278489     7.280753
   7.283655     7.286515     7.288820     7.290805     7.292380
   7.293630     7.294653     7.295467     7.296127     7.296694
   7.297163     7.297535     7.297823     7.298047     7.298222
   7.298362     7.298473     7.298564     7.298636     7.298696
   7.298744     7.298783     7.298814     7.298839     7.298857
   7.298871
BETAT1
 131.281769   131.272356   131.246212   131.223061   131.190830
 131.152542   131.100057   131.044341   130.971196   130.874959
 130.761550   130.623424   130.456048   130.250116   129.982424
 129.669266   129.283355   128.854058   128.385733   127.861015
 127.242161   126.511595   125.711721   124.809808   123.857544
 123.024853   122.618754   122.587236   122.795412   123.133131
 123.582709   124.028165   124.490860   124.887123   125.190549
 125.514202   125.867713   126.185061   126.509030   126.772852
 127.005851   127.182839   127.330880   127.471321   127.568032
 127.651582   127.713520   127.773353   127.810731   127.848052
 127.867114
XTE
  -5.731794    -5.735029    -5.739233    -5.744697    -5.751801
  -5.760493    -5.771126    -5.784135    -5.800049    -5.819518
  -5.843336    -5.872474    -5.908123    -5.951734    -6.005087
  -6.070358    -6.150211    -6.247900    -6.367413    -6.513622
  -6.692492    -6.911319    -7.179029    -7.506539    -7.907212
  -8.397385    -8.887561    -9.288233    -9.615743    -9.883452
 -10.102280   -10.281151   -10.427359   -10.546871   -10.644561
 -10.724414   -10.789686   -10.843039   -10.886650   -10.922299
 -10.951438   -10.975257   -10.994726   -11.010640   -11.023649
 -11.034283   -11.042974   -11.050076   -11.055543   -11.059748
 -11.062981
YTE
   0.000471     0.000471     0.000471     0.000472     0.000471
   0.000470     0.000470     0.000469     0.000469     0.000468
   0.000469     0.000470     0.000471     0.000473     0.000473
   0.000470     0.000468     0.000469     0.000473     0.000473
   0.000472     0.000471     0.000468     0.000475     0.000471
   0.000464     0.000464     0.000468     0.000471     0.000460
   0.000467     0.000467     0.000462     0.000457     0.000460
   0.000466     0.000469     0.000470     0.000467     0.000464
   0.000463     0.000463     0.000463     0.000463     0.000466
   0.000465     0.000467     0.000467     0.000467     0.000468
   0.000468
ZTE
   8.809691     8.809727     8.809773     8.809833     8.809911
   8.810006     8.810122     8.810264     8.810437     8.810648
   8.810906     8.811219     8.811600     8.812058     8.812607
   8.813257     8.814007     8.814852     8.815793     8.816864
   8.818124     8.819621     8.821311     8.823187     8.825278
   8.827568     8.829410     8.830547     8.831099     8.831244
   8.831086     8.830804     8.830573     8.830452     8.830420
   8.830431     8.830447     8.830440     8.830409     8.830365
   8.830317     8.830269     8.830224     8.830184     8.830150
   8.830121     8.830096     8.830075     8.830059     8.830048
   8.830036
BETAT2
  86.977677    86.973932    86.976088    86.973618    86.968883
  86.975419    86.969165    86.970769    86.963695    86.964786
  86.966653    86.968617    86.977814    86.980755    86.998967
  86.987708    86.995244    86.996859    87.022108    87.024978
  87.028719    87.050052    87.087533    87.184788    87.230916
  87.323123    87.347619    87.449030    87.501262    87.537642
  87.590556    87.606019    87.640125    87.669546    87.656125
  87.649347    87.658172    87.670551    87.678676    87.676479
  87.700663    87.709592    87.709429    87.701384    87.694857
```

```
   87.696417     87.686811     87.693660     87.671975     87.677902
   87.682160
```

B.2 R4 Fan, 26 Radial Vanes, Flow-Path Geometry File

```
Flowpath:  Inside Diameter Wall - HUB
   90
 Axial
   -6.492416     -6.223068     -5.953719     -5.684371     -5.415023
   -5.145674     -4.876326     -4.606978     -4.337630     -4.068281
   -3.798933     -3.529585     -3.260236     -2.990888     -2.721540
   -2.452192     -2.182843     -1.913495     -1.644147     -1.374798
   -1.105450     -0.836102     -0.566754     -0.297405     -0.028057
    0.241291      0.510640      0.779988      1.049336      1.318684
    1.588033      1.857381      2.126729      2.396078      2.665426
    2.934774      3.204123      3.473471      3.742819      4.012167
    4.281516      4.550864      4.820212      5.089561      5.358909
    5.628257      5.897605      6.166954      6.436302      6.705650
    6.974999      7.244347      7.513695      7.783043      8.052392
    8.321740      8.591088      8.860437      9.129785      9.399133
    9.668481      9.937830     10.207178     10.476526     10.745875
   11.015223     11.284571     11.553919     11.823268     12.092616
   12.361964     12.631313     12.900661     13.170009     13.439357
   13.708706     13.978054     14.247402     14.516751     14.786099
   15.055447     15.324796     15.594144     15.863492     16.132840
   16.402189     16.671537     16.940885     17.210234     17.479582
 Radius
    2.247375      2.247327      2.247326      2.247418      2.247515
    2.247472      2.247273      2.247887      2.246574      2.265421
    2.293915      2.370075      2.521335      2.670133      2.786873
    2.895937      2.998315      3.094551      3.184809      3.271299
    3.353248      3.430631      3.504568      3.575620      3.645118
    3.714700      3.788526      3.872152      3.962959      4.061083
    4.164406      4.269274      4.373049      4.472974      4.566171
    4.649675      4.724481      4.792390      4.855125      4.913521
    4.968534      5.021084      5.071623      5.119928      5.165138
    5.206371      5.243565      5.279164      5.314289      5.348764
    5.382476      5.416936      5.453929      5.493934      5.537243
    5.583649      5.632728      5.683952      5.736703      5.789956
    5.841779      5.890196      5.933454      5.969981      5.997972
    6.016893      6.028712      6.035462      6.038257      6.038766
    6.039213      6.041073      6.044091      6.047901      6.051907
    6.055678      6.059180      6.062712      6.066678      6.071428
    6.078244      6.087572      6.099421      6.116455      6.138545
    6.164107      6.198385      6.234064      6.280068      6.326072

 Primary Splitter:  Inside Diameter Wall - UPPER
   60
 Axial
    1.588033      1.857381      2.126729      2.396078      2.665426
    2.934774      3.204123      3.473471      3.742819      4.012167
    4.281516      4.550864      4.820212      5.089561      5.358909
    5.628257      5.897605      6.166954      6.436302      6.705650
    6.974999      7.244347      7.513695      7.783043      8.052392
    8.321740      8.591088      8.860437      9.129785      9.399133
    9.668481      9.937830     10.207178     10.476526     10.745875
   11.015223     11.284571     11.553919     11.823268     12.092616
   12.361964     12.631313     12.900661     13.170009     13.439357
   13.708706     13.978054     14.247402     14.516751     14.786099
   15.055447     15.324796     15.594144     15.863492     16.132840
   16.402189     16.671537     16.940885     17.210234     17.479582
 Radius
    4.164406      4.269274      4.373049      4.472974      4.566173
    4.649675      4.724481      4.792390      4.855125      4.913521
    4.968534      5.021083      5.071623      5.119929      5.165137
    5.206370      5.243566      5.279164      5.314288      5.348764
    5.382476      5.416936      5.453929      5.493934      5.537243
    5.583649      5.632729      5.683953      5.736702      5.789956
    5.841779      5.890196      5.933453      5.969981      5.997972
    6.016893      6.028712      6.035463      6.038257      6.038766
```

6.039213	6.041073	6.044092	6.047901	6.051906
6.055678	6.059180	6.062712	6.066677	6.071427
6.078244	6.087572	6.099422	6.116455	6.138545
6.164107	6.198385	6.234063	6.280068	6.326072

Primary Splitter: Outside Diameter Wall - LOWER
60
Axial

1.588033	1.857381	2.126729	2.396078	2.665426
2.934774	3.204123	3.473471	3.742819	4.012167
4.281516	4.550864	4.820212	5.089561	5.358909
5.628257	5.897605	6.166954	6.436302	6.705650
6.974999	7.244347	7.513695	7.783043	8.052392
8.321740	8.591088	8.860437	9.129785	9.399133
9.668481	9.937830	10.207178	10.476526	10.745875
11.015223	11.284571	11.553919	11.823268	12.092616
12.361964	12.631313	12.900661	13.170009	13.439357
13.708706	13.978054	14.247402	14.516751	14.786099
15.055447	15.324796	15.594144	15.863492	16.132840
16.402189	16.671537	16.940885	17.210234	17.479582

Radius

4.164406	4.269274	4.373049	4.472974	4.566173
4.649675	4.724481	4.792390	4.855125	4.913521
4.968534	5.021083	5.071623	5.119929	5.165137
5.206370	5.243566	5.279164	5.314288	5.348764
5.382476	5.416936	5.453929	5.493934	5.537243
5.583649	5.632729	5.683953	5.736702	5.789956
5.841779	5.890196	5.933453	5.969981	5.997972
6.016893	6.028712	6.035463	6.038257	6.038766
6.039213	6.041073	6.044092	6.047901	6.051906
6.055678	6.059180	6.062712	6.066677	6.071427
6.078244	6.087572	6.099422	6.116455	6.138545
6.164107	6.198385	6.234063	6.280068	6.326072

Flowpath: Outside Diameter Wall - TIP
90
Axial

-6.492416	-6.223068	-5.953719	-5.684371	-5.415023
-5.145674	-4.876326	-4.606978	-4.337630	-4.068281
-3.798933	-3.529585	-3.260236	-2.990888	-2.721540
-2.452192	-2.182843	-1.913495	-1.644147	-1.374798
-1.105450	-0.836102	-0.566754	-0.297405	-0.028057
0.241291	0.510640	0.779988	1.049336	1.318684
1.588033	1.857381	2.126729	2.396078	2.665426
2.934774	3.204123	3.473471	3.742819	4.012167
4.281516	4.550864	4.820212	5.089561	5.358909
5.628257	5.897605	6.166954	6.436302	6.705650
6.974999	7.244347	7.513695	7.783043	8.052392
8.321740	8.591088	8.860437	9.129785	9.399133
9.668481	9.937830	10.207178	10.476526	10.745875
11.015223	11.284571	11.553919	11.823268	12.092616
12.361964	12.631313	12.900661	13.170009	13.439357
13.708706	13.978054	14.247402	14.516751	14.786099
15.055447	15.324796	15.594144	15.863492	16.132840
16.402189	16.671537	16.940885	17.210234	17.479582

Radius

10.994159	10.995708	10.997211	10.998479	10.999611
11.000604	11.001331	11.001897	11.002274	11.002436
11.002373	11.002075	11.001534	11.000766	10.999738
10.998452	10.996891	10.995056	10.994439	10.989879
10.978711	10.964280	10.950053	10.936799	10.923467
10.909705	10.895572	10.881487	10.868108	10.856521
10.849407	10.848985	10.854277	10.863108	10.874516
10.888883	10.905819	10.924971	10.945792	10.967818

```
   10.989968      11.011576      11.031997      11.050845      11.068482
   11.085019      11.100056      11.113285      11.124435      11.133971
   11.142259      11.149022      11.153910      11.157242      11.159369
   11.159982      11.158829      11.155923      11.151492      11.145803
   11.138692      11.129869      11.119142      11.106721      11.093042
   11.077677      11.060821      11.043626      11.027036      11.011759
   10.999095      10.990629      10.987237      10.989251      10.995330
   11.005777      11.019678      11.035147      11.052036      11.070549
   11.087467      11.103926      11.119437      11.131994      11.141692
   11.149538      11.152595      11.154867      11.149640      11.144413
```

B.2.3 R4 Fan, 26 Radial Vanes, Blade Geometry File

```
NASA SOURCE DIAGNOSTICS FAN ROTOR AIRFOIL DATA
   51
 XLE
   -3.295686      -3.298879      -3.303026      -3.308416      -3.315417
   -3.324162      -3.335084      -3.348720      -3.365741      -3.386981
   -3.413476      -3.446519      -3.487729      -3.539136      -3.603328
   -3.683642      -3.784313      -3.910644      -4.068956      -4.266736
   -4.513378      -4.821414      -5.207716      -5.692122      -6.295592
   -7.050624      -7.811426      -8.415097      -8.905043      -9.303695
   -9.623877      -9.879386     -10.082826     -10.244967     -10.374412
  -10.477855     -10.560608     -10.626843     -10.679855     -10.722278
  -10.756222     -10.783378     -10.805104     -10.822486     -10.836389
  -10.847510     -10.856407     -10.863523     -10.868997     -10.873209
  -10.876449
 YLE
    0.056427       0.058457       0.061095       0.064524       0.068979
    0.074543       0.081487       0.090146       0.100922       0.114295
    0.130812       0.151054       0.175556       0.204670       0.238192
    0.274909       0.313423       0.352781       0.395373       0.447615
    0.515609       0.599317       0.690701       0.791642       0.930631
    1.097366       1.225780       1.358905       1.420966       1.427043
    1.421476       1.419680       1.424119       1.431528       1.439111
    1.445807       1.451040       1.454871       1.457687       1.459782
    1.461363       1.462570       1.463500       1.464224       1.464790
    1.465236       1.465589       1.465866       1.466078       1.466241
    1.466364
 ZLE
   -1.295420      -1.296012      -1.296780      -1.297775      -1.299065
   -1.300669      -1.302661      -1.305130      -1.308180      -1.311932
   -1.316517      -1.322064      -1.328661      -1.336220      -1.344266
   -1.351675      -1.357121      -1.359273      -1.358225      -1.355354
   -1.349844      -1.336267      -1.310679      -1.272984      -1.224527
   -1.163572      -1.117507      -1.098750      -1.085236      -1.071728
   -1.062910      -1.058597      -1.055990      -1.053602      -1.050897
   -1.047908      -1.044928      -1.042170      -1.039766      -1.037743
   -1.036073      -1.034709      -1.033601      -1.032706      -1.031984
   -1.031404      -1.030937      -1.030563      -1.030274      -1.030052
   -1.029880
 BETAT1
   66.841540      66.816244      66.782973      66.742628      66.684322
   66.614716      66.518150      66.399865      66.240827      66.033530
   65.750686      65.367675      64.835810      64.115501      63.168021
   61.994455      60.685341      59.429313      58.194918      56.664497
   54.802421      53.044079      51.019713      48.934801      46.508760
   43.977919      41.697659      39.575252      38.087769      36.851916
   35.809081      35.100383      34.436503      33.762171      33.149025
   32.649496      32.247174      31.915523      31.643164      31.425564
   31.245939      31.101752      30.986446      30.895654      30.819033
   30.759656      30.713830      30.676545      30.646580      30.624292
   30.608500
 XTE
   -4.082717      -4.086298      -4.090950      -4.096994      -4.104844
   -4.114573      -4.126628      -4.141556      -4.160035      -4.182895
   -4.211148      -4.246033      -4.289063      -4.342091      -4.407376
   -4.487660      -4.586259      -4.707234      -4.855577      -5.037379
   -5.260097      -5.533270      -5.869499      -6.283314      -6.791211
   -7.419757      -8.055547      -8.566285      -8.982050      -9.325653
   -9.605659      -9.831043     -10.011789     -10.156722     -10.273268
```

```
 -10.367136    -10.442887    -10.504106    -10.553565    -10.593498
 -10.625720    -10.651714    -10.672677    -10.689579    -10.703205
 -10.714191    -10.723044    -10.730183    -10.735673    -10.739898
 -10.743147
YTE
   0.594647      0.592409      0.589497      0.585710      0.580784
   0.574669      0.567078      0.557661      0.545990      0.531549
   0.513732      0.491851      0.465070      0.432342      0.392370
   0.343696      0.284892      0.214244      0.129193      0.026384
  -0.096933     -0.237556     -0.391579     -0.575531     -0.811666
  -1.074039     -1.267390     -1.428401     -1.531188     -1.563492
  -1.570421     -1.577020     -1.587586     -1.600604     -1.612693
  -1.622781     -1.630252     -1.635178     -1.638336     -1.640410
  -1.641804     -1.642767     -1.643445     -1.643936     -1.644296
  -1.644564     -1.644769     -1.644922     -1.645038     -1.645124
  -1.645189
```

```
ZTE
   1.488260      1.489511      1.491136      1.493245      1.495981
   1.499368      1.503556      1.508729      1.515107      1.522955
   1.532579      1.544324      1.558554      1.575603      1.595679
   1.618781      1.644581      1.672590      1.702783      1.735980
   1.770521      1.792518      1.782631      1.758387      1.716176
   1.628770      1.529363      1.437964      1.360071      1.300310
   1.250155      1.207113      1.172592      1.145717      1.124701
   1.108162      1.095009      1.084454      1.075952      1.069098
   1.063569      1.059109      1.055513      1.052613      1.050275
   1.048391      1.046872      1.045648      1.044706      1.043981
   1.043424
BETAT2
 123.481468    123.359254    123.200188    122.994565    122.724239
 122.390757    121.977183    121.464469    120.828806    120.048482
 119.085037    117.907387    116.482699    114.763998    112.736276
 110.376716    107.717081    104.740096    101.130260     96.493397
  90.782803     84.862107     79.986019     74.797570     68.263904
  59.838861     53.438826     49.173476     45.258485     43.024895
  42.046861     41.267578     40.301317     39.256564     38.427425
  37.915861     37.615470     37.432165     37.300308     37.201853
  37.121897     37.055565     37.000673     36.955570     36.922893
  36.894533     36.866287     36.849766     36.828928     36.820111
  36.812206
```

B.2.4 R4 Fan, 26 Radial Vanes, Vane Geometry File

```
NASA SOURCE DIAGNOSTICS VANE STATOR AIRFOIL DATA
   51
XLE
  -5.356835     -5.360157     -5.364475     -5.370089     -5.377387
  -5.386353     -5.397370     -5.410906     -5.427534     -5.447961
  -5.473057     -5.503883     -5.541746     -5.588244     -5.645342
  -5.715442     -5.801483     -5.907064     -6.036592     -6.195462
  -6.390305     -6.629235     -6.922182     -7.281330     -7.721694
  -8.261791     -8.801073     -9.239424     -9.595829     -9.885674
 -10.121456    -10.313321    -10.469486    -10.596599    -10.700069
 -10.784289    -10.852844    -10.908639    -10.954050    -10.991011
 -11.021088    -11.045566    -11.065489    -11.081700    -11.094894
 -11.105632    -11.114369    -11.121482    -11.126953    -11.131159
 -11.134397
YLE
  -0.815912     -0.815544     -0.815065     -0.814440     -0.813627
  -0.812628     -0.811398     -0.809889     -0.808038     -0.805765
  -0.802971     -0.799538     -0.795330     -0.790184     -0.783910
  -0.776304     -0.767166     -0.756316     -0.743606     -0.728903
  -0.712053     -0.693055     -0.672365     -0.650916     -0.629767
  -0.609960     -0.595816     -0.589100     -0.587397     -0.588667
  -0.591009     -0.593001     -0.594158     -0.594544     -0.594373
  -0.593860     -0.593188     -0.592481     -0.591817     -0.591215
  -0.590691     -0.590242     -0.589865     -0.589551     -0.589292
```

```
  -0.589079    -0.588906    -0.588762    -0.588652    -0.588567
  -0.588500
ZLE
   7.257049     7.257068     7.257093     7.257125     7.257167
   7.257218     7.257281     7.257359     7.257452     7.257568
   7.257712     7.257887     7.258101     7.258362     7.258680
   7.259070     7.259542     7.260114     7.260808     7.261654
   7.262699     7.263993     7.265561     7.267423     7.269702
   7.272570     7.275416     7.277711     7.279691     7.281259
   7.282502     7.283514     7.284327     7.284987     7.285530
   7.285976     7.286336     7.286622     7.286847     7.287024
   7.287163     7.287273     7.287362     7.287434     7.287490
   7.287536     7.287573     7.287602     7.287625     7.287643
   7.287657
BETAT1
 129.750477   129.739334   129.724029   129.711335   129.690163
 129.665530   129.627791   129.589303   129.534697   129.468759
 129.389145   129.295995   129.175876   129.030101   128.849841
 128.634655   128.374227   128.078744   127.740472   127.359260
 126.954853   126.491982   125.966723   125.376778   124.699379
 123.996106   123.539135   123.403865   123.483888   123.711160
 124.029141   124.390496   124.777101   125.162297   125.546844
 125.924712   126.260976   126.563697   126.826379   127.055075
 127.246984   127.406053   127.541061   127.648344   127.744013
 127.814372   127.877335   127.926293   127.960454   127.987897
 128.006387
XTE
  -5.968562    -5.971792    -5.975988    -5.981445    -5.988539
  -5.997199    -6.007771    -6.020678    -6.036434    -6.055669
  -6.079152    -6.107820    -6.142817    -6.185543    -6.237701
  -6.301377    -6.379113    -6.474012    -6.589866    -6.731300
  -6.903964    -7.114753    -7.372083    -7.686234    -8.069750
  -8.537947    -9.006143    -9.389659    -9.703811    -9.961140
 -10.171928   -10.344593   -10.486028   -10.601881   -10.696780
 -10.774516   -10.838192   -10.890350   -10.933077   -10.968074
 -10.996741   -11.020225   -11.039460   -11.055216   -11.068122
 -11.078694   -11.087355   -11.094450   -11.099905   -11.104103
 -11.107331
YTE
   0.000849     0.000848     0.000849     0.000849     0.000849
   0.000848     0.000848     0.000849     0.000849     0.000849
   0.000851     0.000850     0.000850     0.000848     0.000847
   0.000849     0.000849     0.000849     0.000844     0.000838
   0.000838     0.000831     0.000875     0.001030     0.000992
   0.001001     0.000991     0.000989     0.000989     0.000985
   0.000983     0.000990     0.000991     0.000987     0.000987
   0.000995     0.001000     0.000995     0.000991     0.000991
   0.000995     0.000995     0.000994     0.000992     0.000989
   0.000991     0.000989     0.000990     0.000991     0.000992
   0.000993

ZTE
  10.464846    10.464897    10.464964    10.465050    10.465163
  10.465301    10.465467    10.465672    10.465922    10.466226
  10.466595    10.467046    10.467589    10.468244    10.469028
  10.469959    10.471045    10.472282    10.473650    10.475088
  10.476458    10.477498    10.478033    10.478429    10.478971
  10.478994    10.477524    10.475833    10.473969    10.472043
  10.470109    10.468323    10.466953    10.466063    10.465543
  10.465265    10.465103    10.464980    10.464857    10.464729
  10.464599    10.464472    10.464359    10.464258    10.464171
  10.464100    10.464039    10.463988    10.463948    10.463918
  10.463894
BETAT2
  87.543584    87.541705    87.539768    87.537604    87.537903
  87.535262    87.531083    87.532151    87.526585    87.529965
  87.534993    87.532980    87.522486    87.499900    87.500703
  87.508280    87.492757    87.482505    87.464872    87.468266
```

87.456714	87.435190	87.431004	87.438093	87.415635
87.417438	87.407650	87.418157	87.422962	87.418133
87.410126	87.400043	87.402715	87.405149	87.408546
87.391481	87.363950	87.359101	87.372998	87.389326
87.389493	87.387180	87.397875	87.397881	87.398400
87.395349	87.389629	87.387746	87.388776	87.378480
87.377135				

B.3 R4 Fan, 26 Swept Vanes, Flow-Path Geometry File

Flowpath: Inside Diameter Wall - HUB

90

Axial

-6.581012	-6.307988	-6.034964	-5.761940	-5.488917
-5.215893	-4.942869	-4.669845	-4.396821	-4.123797
-3.850774	-3.577750	-3.304726	-3.031702	-2.758678
-2.485655	-2.212631	-1.939607	-1.666583	-1.393559
-1.120536	-0.847512	-0.574488	-0.301464	-0.028440
0.244583	0.517607	0.790631	1.063655	1.336679
1.609702	1.882726	2.155750	2.428774	2.701798
2.974822	3.247845	3.520869	3.793893	4.066917
4.339941	4.612964	4.885988	5.159012	5.432036
5.705060	5.978083	6.251107	6.524131	6.797155
7.070179	7.343202	7.616226	7.889250	8.162274
8.435298	8.708322	8.981345	9.254369	9.527393
9.800417	10.073441	10.346464	10.619488	10.892512
11.165536	11.438560	11.711583	11.984607	12.257631
12.530655	12.803679	13.076702	13.349726	13.622750
13.895774	14.168798	14.441822	14.714845	14.987869
15.260893	15.533917	15.806941	16.079964	16.352988
16.626012	16.899036	17.172060	17.445083	17.718107

Radius

2.278043	2.277993	2.277993	2.278086	2.278184
2.278141	2.277939	2.278562	2.277231	2.296334
2.325218	2.402416	2.555741	2.706569	2.824902
2.935455	3.039230	3.136779	3.228269	3.315939
3.399007	3.477445	3.552391	3.624413	3.694859
3.765390	3.840224	3.924991	4.017037	4.116500
4.221233	4.327530	4.432723	4.534007	4.628337
4.713060	4.789160	4.857886	4.921322	4.980497
5.036348	5.089725	5.141061	5.190151	5.235796
5.277146	5.315005	5.351330	5.387377	5.421951
5.453787	5.483371	5.511820	5.540183	5.568631
5.596844	5.624491	5.651341	5.677274	5.702190
5.725983	5.748543	5.769778	5.789558	5.807803
5.824373	5.839240	5.852539	5.864429	5.875103
5.884788	5.893738	5.902256	5.910888	5.920390
5.931762	5.946565	5.965664	5.988472	6.014392
6.043109	6.074581	6.109252	6.146275	6.185302
6.227963	6.272015	6.317506	6.364912	6.412795

Primary Splitter: Inside Diameter Wall - UPPER

60

Axial

1.609702	1.882726	2.155750	2.428774	2.701798
2.974822	3.247845	3.520869	3.793893	4.066917
4.339941	4.612964	4.885988	5.159012	5.432036
5.705060	5.978083	6.251107	6.524131	6.797155
7.070179	7.343202	7.616226	7.889250	8.162274
8.435298	8.708322	8.981345	9.254369	9.527393
9.800417	10.073441	10.346464	10.619488	10.892512
11.165536	11.438560	11.711583	11.984607	12.257631
12.530655	12.803679	13.076702	13.349726	13.622750
13.895774	14.168798	14.441822	14.714845	14.987869
15.260893	15.533917	15.806941	16.079964	16.352988
16.626012	16.899036	17.172060	17.445083	17.718107

Radius

4.221233	4.327531	4.432723	4.534007	4.628337
4.713060	4.789162	4.857885	4.921322	4.980496
5.036348	5.089725	5.141060	5.190150	5.235795

5.277147	5.315006	5.351330	5.387377	5.421950
5.453787	5.483371	5.511820	5.540183	5.568630
5.596844	5.624491	5.651341	5.677274	5.702190
5.725983	5.748543	5.769778	5.789558	5.807803
5.824374	5.839240	5.852539	5.864429	5.875103
5.884788	5.893738	5.902256	5.910887	5.920390
5.931762	5.946565	5.965664	5.988472	6.014391
6.043109	6.074581	6.109251	6.146275	6.185302
6.227963	6.272015	6.317507	6.364912	6.412795

Primary Splitter: Outside Diameter Wall - LOWER

60

Axial

1.609702	1.882726	2.155750	2.428774	2.701798
2.974822	3.247845	3.520869	3.793893	4.066917
4.339941	4.612964	4.885988	5.159012	5.432036
5.705060	5.978083	6.251107	6.524131	6.797155
7.070179	7.343202	7.616226	7.889250	8.162274
8.435298	8.708322	8.981345	9.254369	9.527393
9.800417	10.073441	10.346464	10.619488	10.892512
11.165536	11.438560	11.711583	11.984607	12.257631
12.530655	12.803679	13.076702	13.349726	13.622750
13.895774	14.168798	14.441822	14.714845	14.987869
15.260893	15.533917	15.806941	16.079964	16.352988
16.626012	16.899036	17.172060	17.445083	17.718107

Radius

4.221233	4.327531	4.432723	4.534007	4.628337
4.713060	4.789162	4.857885	4.921322	4.980496
5.036348	5.089725	5.141060	5.190150	5.235795
5.277147	5.315006	5.351330	5.387377	5.421950
5.453787	5.483371	5.511820	5.540183	5.568630
5.596844	5.624491	5.651341	5.677274	5.702190
5.725983	5.748543	5.769778	5.789558	5.807803
5.824374	5.839240	5.852539	5.864429	5.875103
5.884788	5.893738	5.902256	5.910887	5.920390
5.931762	5.946565	5.965664	5.988472	6.014391
6.043109	6.074581	6.109251	6.146275	6.185302
6.227963	6.272015	6.317507	6.364912	6.412795

Flowpath: Outside Diameter Wall - TIP

90

Axial

-6.581012	-6.307988	-6.034964	-5.761940	-5.488916
-5.215893	-4.942869	-4.669845	-4.396821	-4.123797
-3.850773	-3.577749	-3.304726	-3.031702	-2.758678
-2.485654	-2.212630	-1.939606	-1.666582	-1.393559
-1.120535	-0.847511	-0.574487	-0.301463	-0.028439
0.244585	0.517608	0.790632	1.063656	1.336680
1.609704	1.882728	2.155751	2.428775	2.701799
2.974823	3.247847	3.520871	3.793895	4.066918
4.339942	4.612966	4.885990	5.159014	5.432038
5.705062	5.978085	6.251109	6.524133	6.797157
7.070181	7.343205	7.616229	7.889252	8.162276
8.435300	8.708324	8.981348	9.254372	9.527395
9.800419	10.073443	10.346467	10.619491	10.892515
11.165539	11.438562	11.711586	11.984610	12.257634
12.530658	12.803682	13.076706	13.349729	13.622753
13.895777	14.168801	14.441825	14.714849	14.987873
15.260896	15.533920	15.806944	16.079968	16.352992
16.626016	16.899039	17.172063	17.445087	17.718111

Radius

11.144184	11.145755	11.147279	11.148565	11.149713
11.150718	11.151455	11.152029	11.152410	11.152576
11.152512	11.152209	11.151661	11.150883	11.149840

```
   11.148537     11.146954     11.145094     11.144468     11.139848
   11.128527     11.113897     11.099478     11.086043     11.072528
   11.058579     11.044253     11.029975     11.016415     11.004662
   10.997435     10.996941     11.002361     11.011303     11.023008
   11.037576     11.054704     11.074055     11.095138     11.117540
   11.139788     11.161870     11.182139     11.202155     11.215710
   11.229100     11.236480     11.242274     11.244181     11.243522
   11.240329     11.235912     11.228514     11.220239     11.210999
   11.201222     11.191209     11.180980     11.170924     11.161669
   11.153554     11.146475     11.141077     11.138075     11.136992
   11.136987     11.137149     11.137113     11.137054     11.137110
   11.137225     11.136878     11.136743     11.139054     11.144890
   11.155511     11.169943     11.185459     11.202701     11.221603
   11.238830     11.255937     11.271424     11.284403     11.294512
   11.301850     11.306308     11.306928     11.303662     11.296490
```

B.3.5 B-4b. R4 Fan, 26 Swept Vanes, Blade Geometry File

```
NASA SOURCE DIAGNOSTICS FAN ROTOR AIRFOIL DATA
   51
 XLE
   -3.340660     -3.343895     -3.348099     -3.353562     -3.360659
   -3.369524     -3.380594     -3.394417     -3.411670     -3.433199
   -3.460056     -3.493551     -3.535323     -3.587431     -3.652499
   -3.733908     -3.835954     -3.964009     -4.124481     -4.324960
   -4.574967     -4.887207     -5.278780     -5.769798     -6.381501
   -7.146836     -7.918021     -8.529930     -9.026561     -9.430654
   -9.755203    -10.014200    -10.220415    -10.384768    -10.515981
  -10.620836    -10.704718    -10.771857    -10.825593    -10.868594
  -10.903000    -10.930528    -10.952551    -10.970168    -10.984262
  -10.995536    -11.004554    -11.011766    -11.017315    -11.021585
  -11.024868
 YLE
    0.057197      0.059255      0.061929      0.065404      0.069920
    0.075560      0.082599      0.091376      0.102299      0.115854
    0.132597      0.153115      0.177951      0.207463      0.241442
    0.278660      0.317700      0.357595      0.400768      0.453723
    0.522645      0.607495      0.700126      0.802445      0.943330
    1.112341      1.242507      1.377449      1.440356      1.446517
    1.440873      1.439054      1.443552      1.451062      1.458749
    1.465537      1.470841      1.474725      1.477579      1.479702
    1.481305      1.482528      1.483471      1.484205      1.484778
    1.485230      1.485588      1.485869      1.486084      1.486250
    1.486374
 ZLE
   -1.313097     -1.313697     -1.314476     -1.315485     -1.316792
   -1.318418     -1.320437     -1.322940     -1.326032     -1.329835
   -1.334482     -1.340105     -1.346792     -1.354454     -1.362610
   -1.370120     -1.375640     -1.377821     -1.376760     -1.373849
   -1.368264     -1.354501     -1.328564     -1.290355     -1.241237
   -1.179450     -1.132756     -1.113743     -1.100046     -1.086353
   -1.077415     -1.073043     -1.070400     -1.067979     -1.065237
   -1.062208     -1.059187     -1.056392     -1.053954     -1.051904
   -1.050211     -1.048828     -1.047706     -1.046798     -1.046067
   -1.045478     -1.045005     -1.044626     -1.044333     -1.044108
   -1.043934
 BETAT1
   66.841920     66.816213     66.783037     66.742464     66.684126
   66.614647     66.518016     66.399774     66.240639     66.033436
   65.750527     65.367774     64.835723     64.115307     63.167938
   61.994326     60.685563     59.429369     58.194911     56.664573
   54.802536     53.044212     51.019993     48.934833     46.509207
   43.978321     41.697665     39.574961     38.088167     36.851786
   35.809419     35.100186     34.436220     33.761689     33.148814
   32.649151     32.247034     31.915376     31.642890     31.425661
   31.245482     31.101810     30.986606     30.896034     30.819014
   30.759578     30.713482     30.675800     30.646528     30.624456
   30.608658
 XTE
   -4.138430     -4.142060     -4.146776     -4.152902     -4.160859
   -4.170722     -4.182940     -4.198072     -4.216804     -4.239974
```

```
   -4.268613     -4.303975     -4.347592     -4.401343     -4.467519
   -4.548899     -4.648844     -4.771470     -4.921836     -5.106120
   -5.331875     -5.608778     -5.949595     -6.369057     -6.883883
   -7.521008     -8.165472     -8.683180     -9.104619     -9.452910
   -9.736737     -9.965199    -10.148410    -10.295321    -10.413456
  -10.508606    -10.585391    -10.647445    -10.697579    -10.738056
  -10.770720    -10.797068    -10.818316    -10.835448    -10.849261
  -10.860396    -10.869372    -10.876607    -10.882173    -10.886454
  -10.889748
 YTE
    0.602761      0.600492      0.597541      0.593703      0.588709
    0.582510      0.574816      0.565271      0.553440      0.538802
    0.520742      0.498563      0.471417      0.438242      0.397724
    0.348386      0.288779      0.217166      0.130956      0.026743
   -0.098256     -0.240798     -0.396923     -0.583385     -0.822741
   -1.088696     -1.284685     -1.447893     -1.552084     -1.584827
   -1.591851     -1.598540     -1.609250     -1.622446     -1.634700
   -1.644926     -1.652498     -1.657492     -1.660693     -1.662795
   -1.664208     -1.665184     -1.665872     -1.666369     -1.666734
   -1.667006     -1.667213     -1.667369     -1.667487     -1.667573
   -1.667639
```

```
 ZTE
    1.508569      1.509837      1.511484      1.513622      1.516396
    1.519828      1.524073      1.529317      1.535782      1.543737
    1.553493      1.565398      1.579822      1.597104      1.617454
    1.640871      1.667023      1.695415      1.726019      1.759669
    1.794682      1.816979      1.806956      1.782382      1.739595
    1.650995      1.550232      1.457586      1.378630      1.318054
    1.267215      1.223585      1.188594      1.161352      1.140049
    1.123284      1.109952      1.099252      1.090634      1.083687
    1.078082      1.073562      1.069916      1.066977      1.064607
    1.062697      1.061157      1.059916      1.058962      1.058227
    1.057662
 BETAT2
  123.481490    123.359128    123.199538    122.994199    122.723999
  122.390886    121.977428    121.464103    120.829208    120.048846
  119.085069    117.907460    116.482743    114.764342    112.735963
  110.376617    107.716938    104.740458    101.130253     96.493585
   90.782524     84.861963     79.985831     74.797611     68.264318
   59.839296     53.438460     49.173302     45.258691     43.025093
   42.046849     41.267239     40.301294     39.256844     38.427290
   37.915810     37.615249     37.432006     37.300492     37.201673
   37.122089     37.054914     37.000237     36.955278     36.922331
   36.894595     36.866235     36.849618     36.828841     36.820435
   36.812225
```

B.3.6 R4 Fan, 26 Swept Vanes, Vane Geometry File

```
NASA SOURCE DIAGNOSTICS VANE STATOR AIRFOIL DATA
   51
 XLE
   -5.436280     -5.439158     -5.442898     -5.447761     -5.454082
   -5.461904     -5.471583     -5.483561     -5.498379     -5.516716
   -5.539403     -5.567472     -5.602200     -5.645162     -5.698305
   -5.764034     -5.845315     -5.945811     -6.070047     -6.223644
   -6.413625     -6.648677     -6.939284     -7.298377     -7.742211
   -8.290494     -8.838033     -9.280193     -9.637332     -9.925845
  -10.158876    -10.346982    -10.498800    -10.621397    -10.720419
  -10.800375    -10.864911    -10.916997    -10.959044    -10.993000
  -11.020428    -11.042585    -11.060489    -11.074954    -11.086639
  -11.096085    -11.103716    -11.109882    -11.114625    -11.118274
  -11.121081
 YLE
   -0.795390     -0.795226     -0.795011     -0.794732     -0.794368
   -0.793918     -0.793359     -0.792669     -0.791815     -0.790761
   -0.789458     -0.787847     -0.785854     -0.783396     -0.780383
   -0.776725     -0.772351     -0.767202     -0.761226     -0.754169
```

```
   -0.744985     -0.732126     -0.715833     -0.696765     -0.673254
   -0.647653     -0.624627     -0.605792     -0.590409     -0.577678
   -0.568304     -0.563855     -0.563534     -0.564812     -0.566707
   -0.569411     -0.573070     -0.577260     -0.581446     -0.585243
   -0.588533     -0.591309     -0.593618     -0.595519     -0.597070
   -0.598334     -0.599362     -0.600195     -0.600838     -0.601335
   -0.601717
 ZLE
    7.446051      7.447709      7.449862      7.452662      7.456302
    7.460806      7.466381      7.473278      7.481812      7.492373
    7.505443      7.521616      7.541629      7.566395      7.597041
    7.634959      7.681865      7.739886      7.811643      7.900407
    8.010277      8.146364      8.314905      8.523576      8.781817
    9.101016      9.420207      9.677826      9.886405     10.054845
   10.190549     10.300364     10.389606     10.461797     10.519979
   10.566864     10.604698     10.635252     10.659930     10.679867
   10.695974     10.708991     10.719511     10.728012     10.734879
   10.740430     10.744915     10.748541     10.751328     10.753473
   10.755123
 BETAT1
  129.873150    129.863295    129.848513    129.827107    129.802346
  129.773619    129.736074    129.693068    129.638014    129.568716
  129.481512    129.368901    129.229323    129.064198    128.857568
  128.607673    128.314696    127.973795    127.575615    127.130741
  126.605518    125.962763    125.200603    124.386658    123.410217
  122.396922    121.571660    120.986038    120.658848    120.525876
  120.574000    120.771182    121.134839    121.499509    121.811339
  122.113521    122.448580    122.789434    123.115802    123.399654
  123.642627    123.849998    124.012872    124.147636    124.263409
  124.352260    124.429915    124.487676    124.540279    124.578784
  124.608518
 XTE
   -5.808912     -5.811751     -5.815439     -5.820235     -5.826470
   -5.834159     -5.843640     -5.855333     -5.869753     -5.887536
   -5.909467     -5.936511     -5.969862     -6.010993     -6.061715
   -6.124266     -6.201406     -6.296534     -6.413849     -6.558524
   -6.736938     -6.956962     -7.228297     -7.562913     -7.975567
   -8.484455     -8.993346     -9.405998     -9.740613    -10.011949
  -10.231968    -10.410378    -10.555044    -10.672351    -10.767471
  -10.844597    -10.907134    -10.957841    -10.998956    -11.032294
  -11.059325    -11.081243    -11.099017    -11.113427    -11.125114
  -11.134590    -11.142273    -11.148503    -11.153296    -11.156983
  -11.159819
 YTE
    0.001041      0.001060      0.001082      0.001110      0.001142
    0.001176      0.001206      0.001225      0.001228      0.001215
    0.001204      0.001206      0.001210      0.001206      0.001217
    0.001206      0.001080      0.001023      0.001045      0.001062
    0.001212      0.001035      0.001207      0.001063      0.001136
    0.000984      0.001951      0.002761      0.004607      0.007416
    0.010569      0.014645      0.019606      0.023682      0.027651
    0.032176      0.036805      0.041123      0.045015      0.048511
    0.051551      0.054106      0.056215      0.057949      0.059371
    0.060532      0.061480      0.062252      0.062848      0.063305
    0.063659


 ZTE
   10.909956     10.911592     10.913717     10.916482     10.920075
   10.924505     10.929971     10.936710     10.945022     10.955273
   10.967913     10.983503     11.002730     11.026443     11.055693
   11.091771     11.136288     11.191225     11.259048     11.342788
   11.446181     11.573838     11.731372     11.925663     12.165092
   12.459756     12.754123     12.992770     13.186594     13.343133
   13.469471     13.571556     13.653922     13.720418     13.773914
   13.816706     13.850841     13.878137     13.900045     13.917696
   13.931945     13.943466     13.952789     13.960340     13.966455
   13.971413     13.975430     13.978686     13.981192     13.983118
   13.984600
```

```
BETAT2
  86.816576     86.817569     86.820224     86.821634     86.823566
  86.820002     86.824669     86.826677     86.823118     86.815478
  86.806812     86.799077     86.800492     86.800990     86.804042
  86.797891     86.784666     86.789030     86.794510     86.774798
  86.780127     86.771108     86.758127     86.737510     86.717064
  86.699335     86.678051     86.647505     86.672113     86.679102
  86.647844     86.668759     86.674780     86.657714     86.665654
  86.683688     86.682664     86.681759     86.679799     86.662979
  86.641556     86.640914     86.641261     86.636507     86.625623
  86.627781     86.619108     86.613853     86.606500     86.601761
  86.599825
```

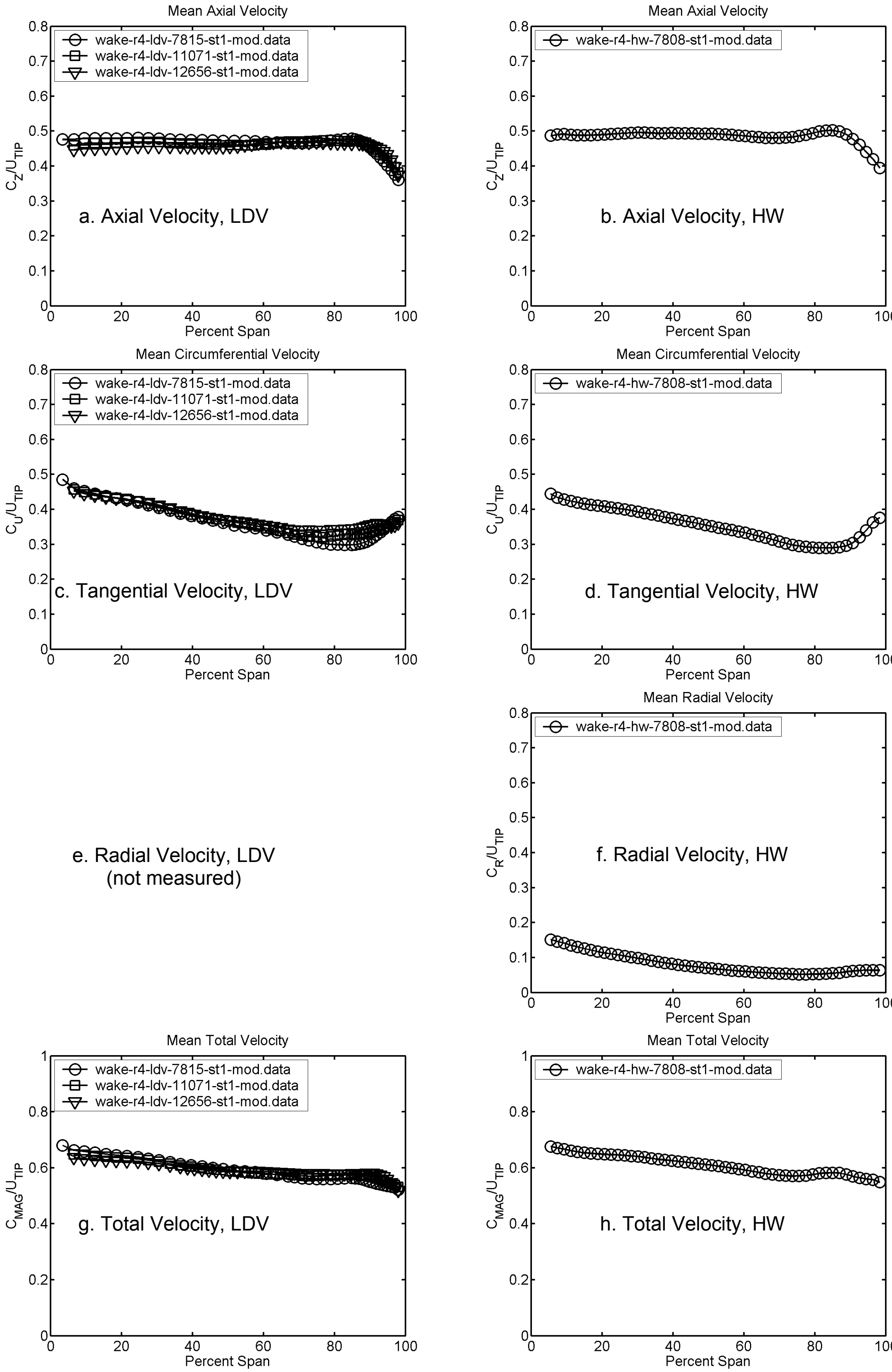


Figure B.2.—R4 fan, average velocity, station A.

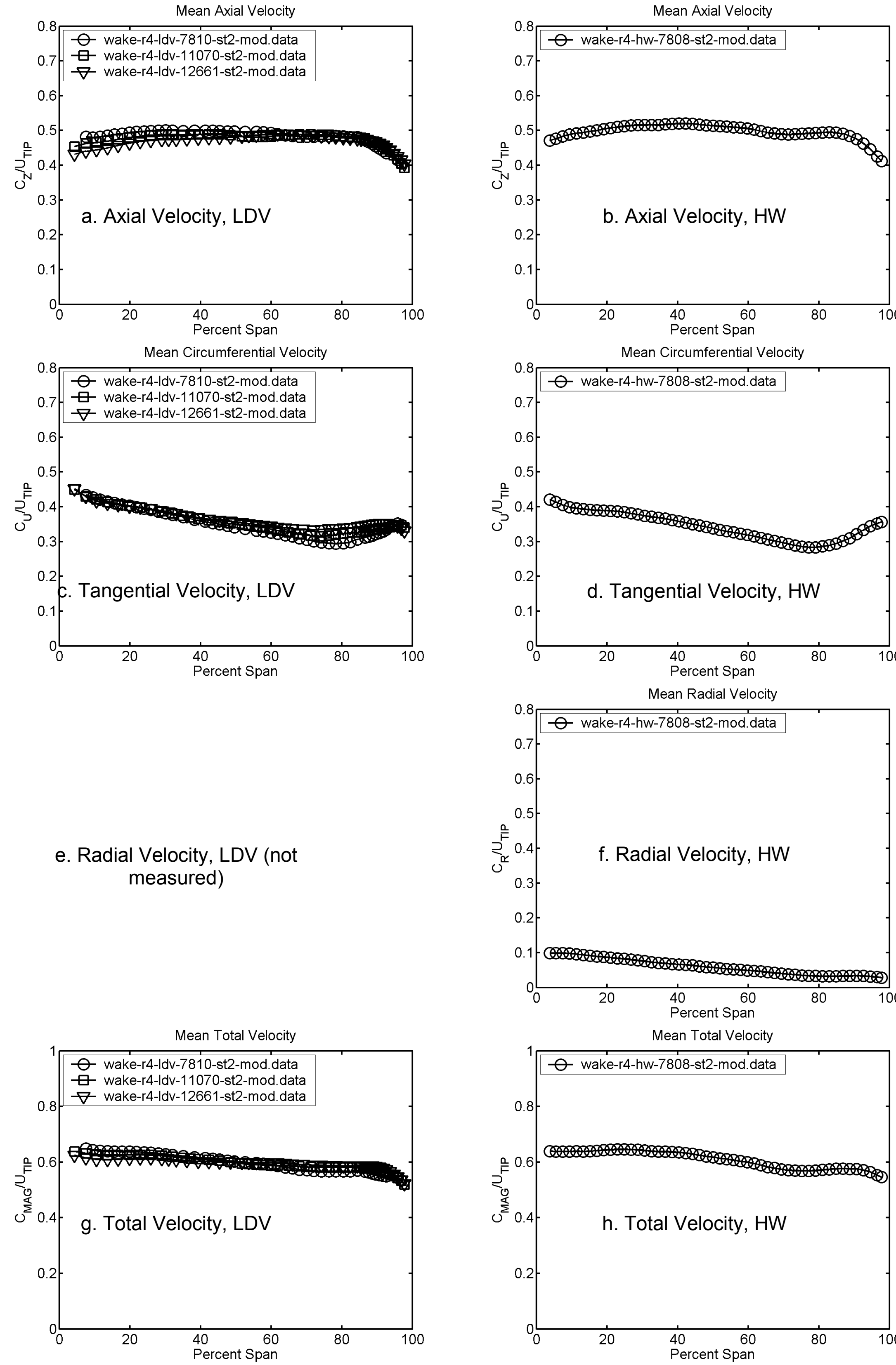


Figure B.3.—R4 fan, average velocity, station B.

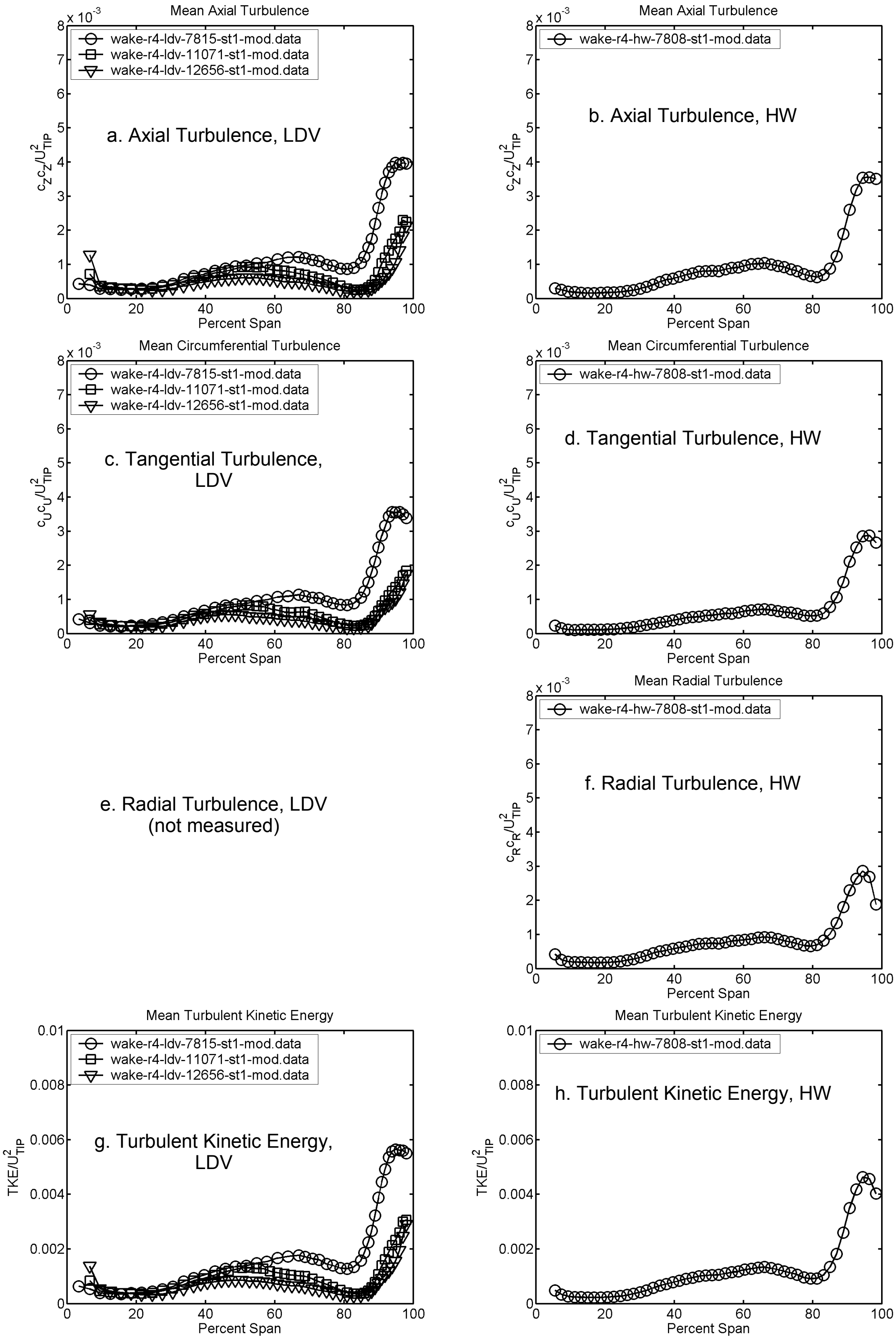


Figure B.4.—R4 fan, average turbulence intensity, station A.

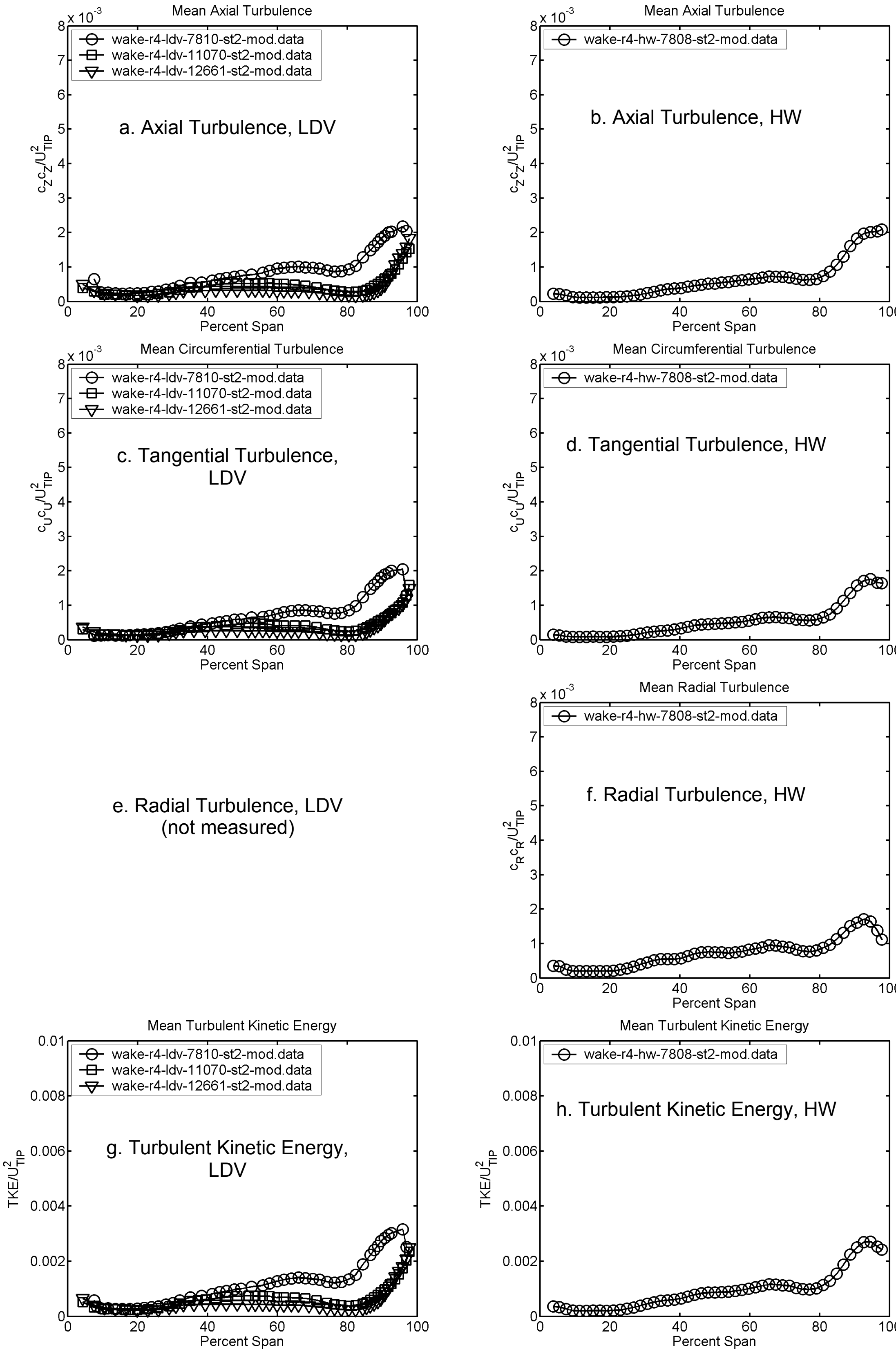


Figure B.5.—R4 fan, average turbulence intensity, station B.

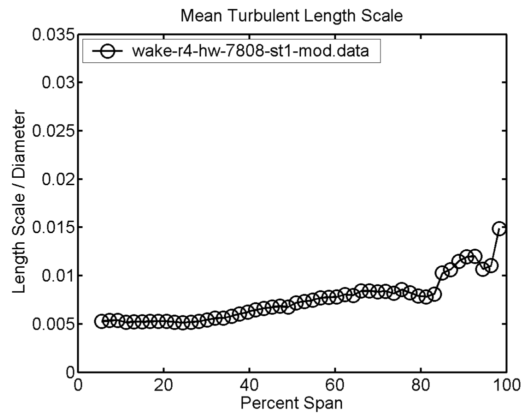


Figure B.6.—R4 fan, average turbulence scale, station A.

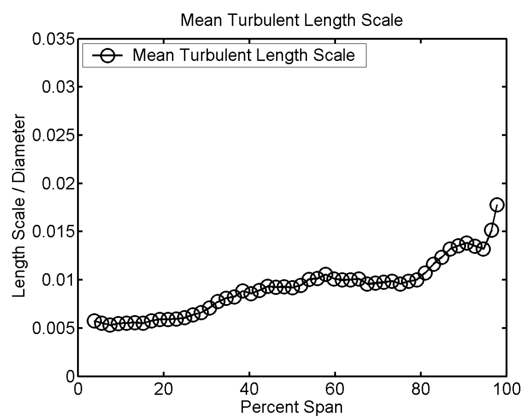


Figure B.7.—R4 fan, average turbulence scale, station B.

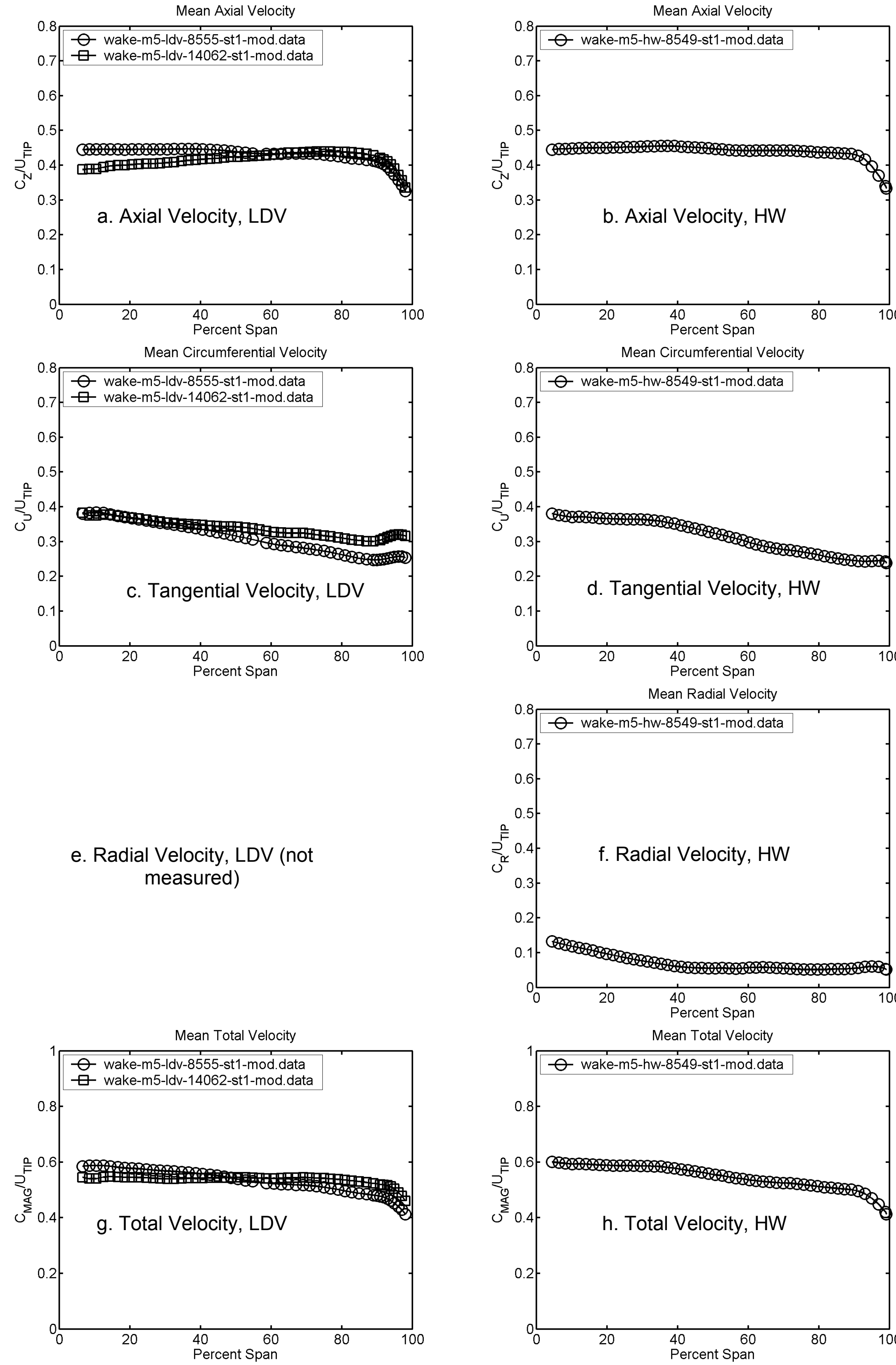


Figure B.8.—M5 fan, average velocity, station A.

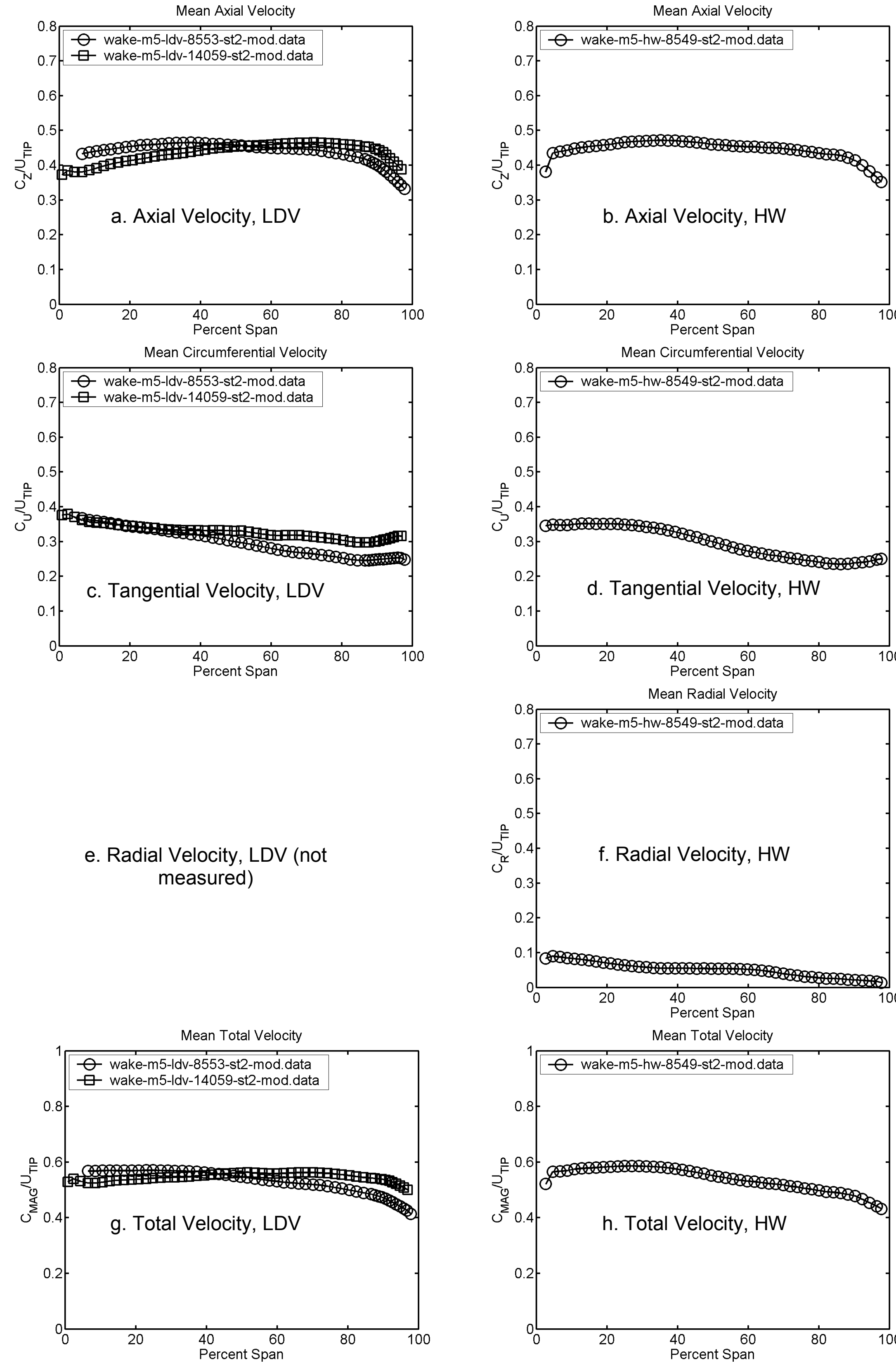


Figure B.9.—M5 fan, average velocity, station B.

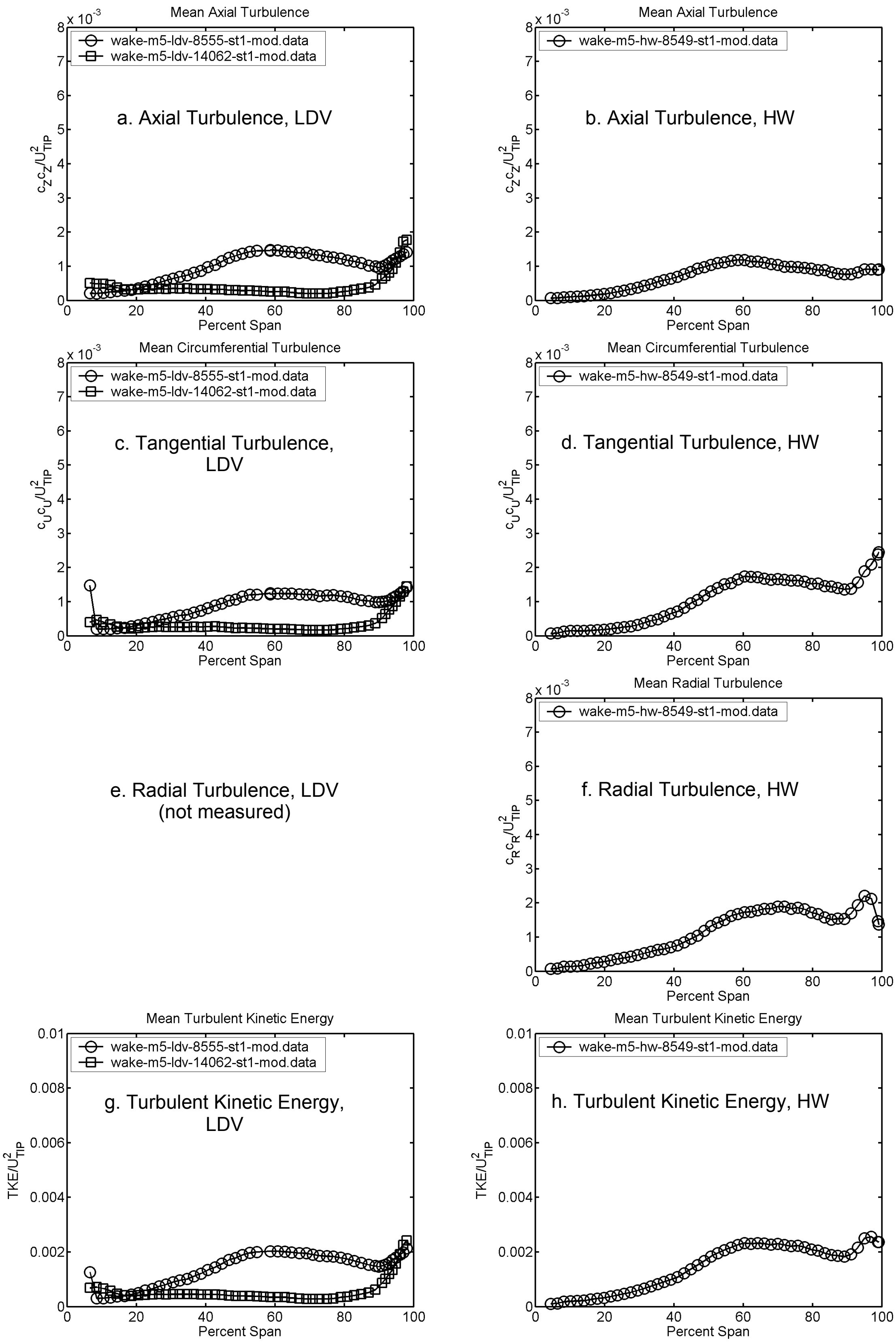


Figure B.10.—M5 fan, average turbulence intensity, station A.

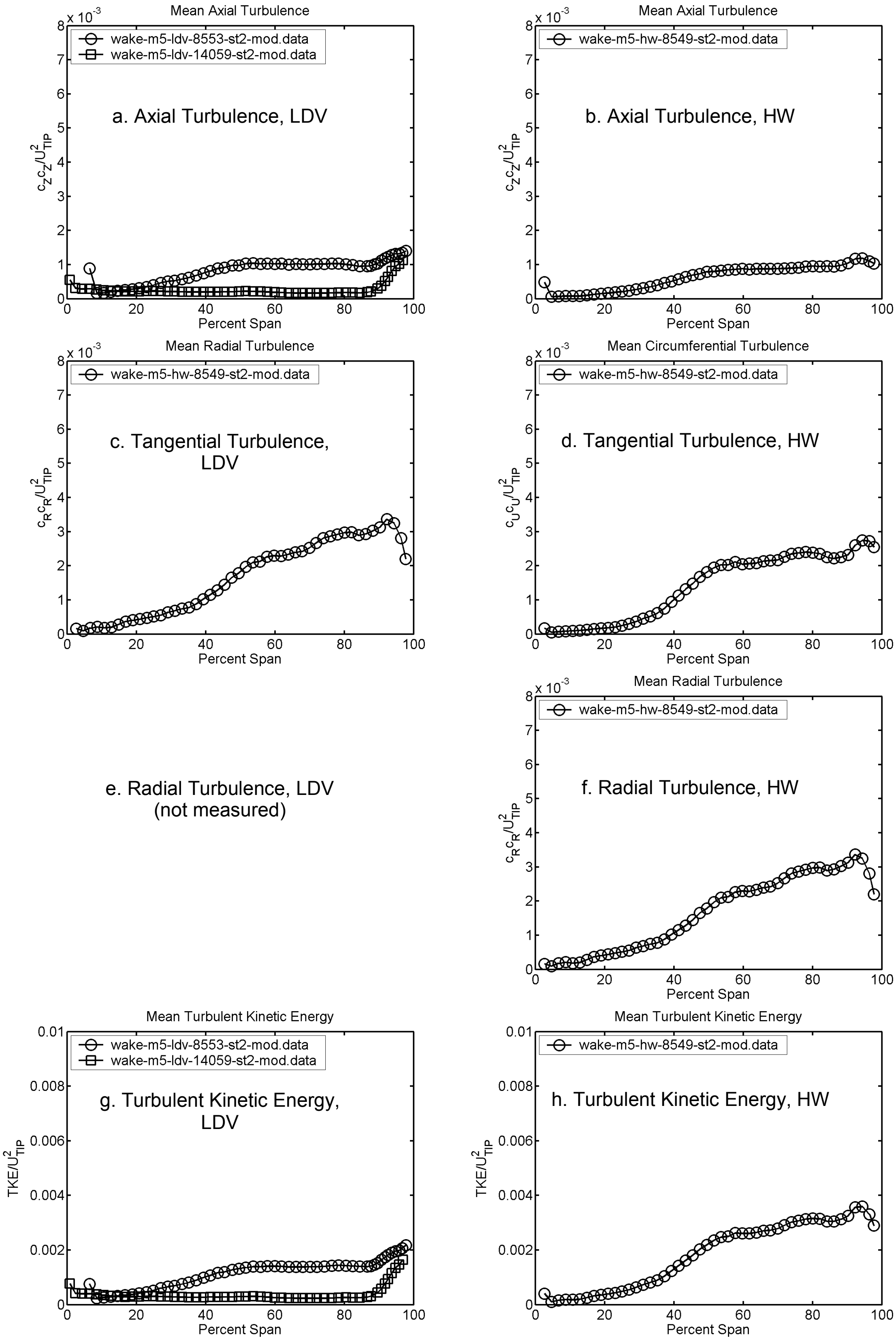


Figure B.11.—R4 fan, average turbulence intensity, station B.

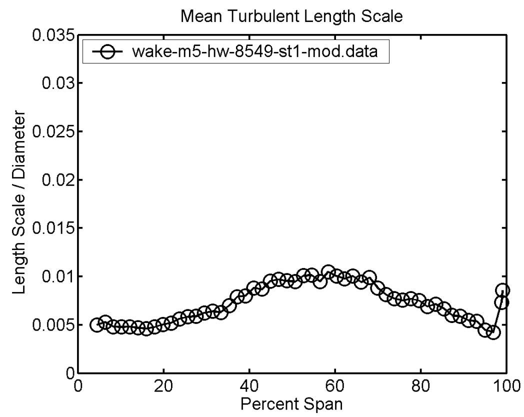


Figure B.12.—M5 fan, average turbulence scale, station A.

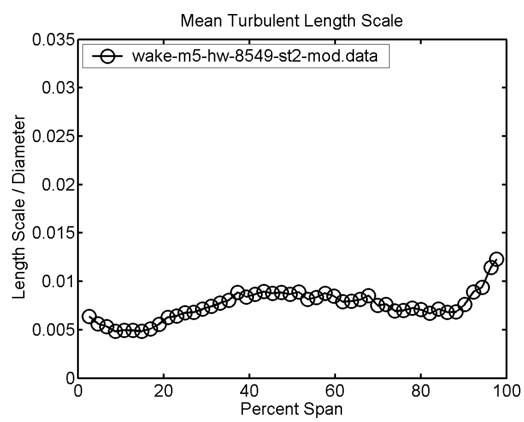


Figure B.13.—M5 fan, average turbulence scale, station B.

Appendix C.—Boeing Fan Rig Information

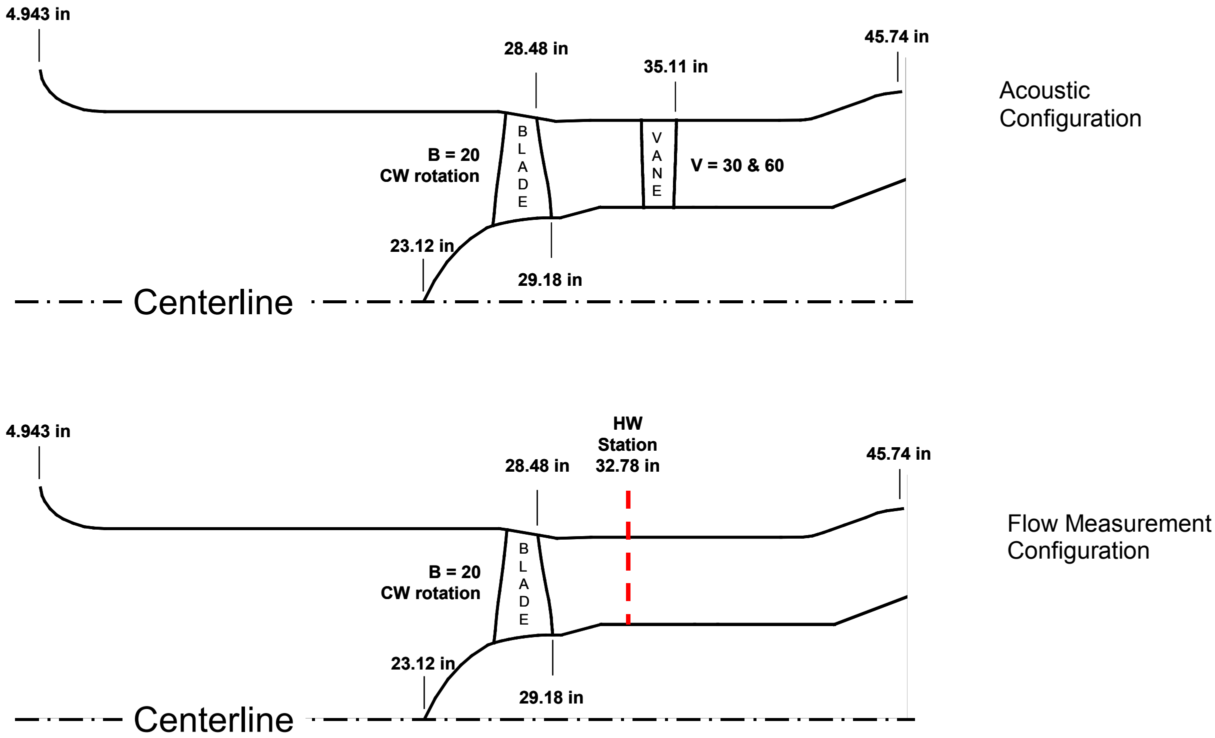


Figure C.1.—Boeing fan rig schematics.

C.1 Geometry Files

C.1.1 Boeing Rig, Flow-Path Geometry File

```
Flowpath: I.D. wall
29
Axial
     23.1170     23.6230     24.2280     24.8360     25.3450     26.1170
     26.3900     26.7374     27.0848     27.4423     27.7797     28.1271
     28.4745     28.8219     29.1693     29.2500     29.6000     31.0000
     31.4700     35.9000     37.0000     42.5200     49.0000     49.5000
     50.0000     50.5000     51.0000     51.5000     54.7533
Radius
      0.0000      0.9888      1.8864      2.5575      3.0022      3.5163
      3.6200      3.7103      3.7880      3.8532      3.9063      3.9474
      3.9766      3.9942      4.0000      4.0000      4.0000      4.3743
      4.5000      4.5000      4.5000      4.5000      6.9800      7.1900
      7.3400      7.4300      7.4800      7.5000      7.5000
Primary Splitter: Duct I.D. wall
11
Axial
     31.4700     35.9000     37.0000     42.5200     49.0000     49.5000
     50.0000     50.5000     51.0000     51.5000     54.7533
Radius
      4.5000      4.5000      4.5000      4.5000      6.9800      7.1900
      7.3400      7.4300      7.4800      7.5000      7.5000
Primary Splitter: Core O.D. wall
11
Axial
     31.4700     35.9000     37.0000     42.5200     49.0000     49.5000
```

```
    50.0000     50.5000     51.0000     51.5000     54.7533
Radius
     4.5000      4.5000      4.5000      4.5000      6.9800      7.1900
     7.3400      7.4300      7.4800      7.5000      7.5000
Flowpath: O.D. wall
28
Axial
     4.9429      5.0150      5.1438      5.3966      5.7069      6.0147
     6.4818      7.0105      7.4589      7.9989     26.6700     27.0630
    28.5250     28.9690     29.3790     31.0000     39.9853     40.9935
    41.2438     41.4794     41.7104     41.9961     42.3073     42.9881
    44.0022     44.5470     44.9914     45.7425
Radius
    10.9952     10.6302     10.3620     10.0090      9.7160      9.5257
     9.3174      9.1546      9.0962      9.0625      9.0625      9.0000
     8.7500      8.6700      8.6000      8.6500      8.6500      8.6546
     8.6802      8.7118      8.7800      8.8752      8.9857      9.2302
     9.5895      9.8086      9.9114     10.0073
```

C.1.2 Boeing Rig, Blade Geometry File

```
BOEING NOISE RESEARCH FAN ROTOR AIRFOIL DATA
   13
 XLE
     3.561559        3.639948        3.835290        4.130931        4.507303
     4.944070        5.426711        5.961138        6.514472        7.082766
     7.664885        8.259810        8.882345
 YLE
     -.654542        -.671351        -.721084        -.795199        -.888330
     -.988913       -1.079903       -1.152941       -1.219800       -1.269694
    -1.320424       -1.392598       -1.442951
 ZLE
    26.395505       26.409969       26.432180       26.463606       26.498208
    26.543040       26.601611       26.675780       26.748059       26.823387
    26.893716       26.954570       27.020048
 BETA1
    57.857351       56.483573       53.607210       50.185181       46.688229
    43.138043       39.729072       36.696557       34.150685       31.799668
    29.371879       26.976377       23.840608
 XTE
     3.994701        4.061711        4.229500        4.483066        4.805972
     5.180914        5.596003        6.058247        6.540309        7.039913
     7.553667        8.080504        8.640662
 YTE
      .207561         .242441         .326880         .448857         .595086
      .748331         .886733        1.001627        1.098912        1.170944
     1.235934        1.316475        1.375659
 ZTE
    29.179786       29.170911       29.161129       29.141444       29.111954
    29.063591       28.992426       28.898010       28.805873       28.711970
    28.627272       28.556980       28.479465
 BETA2
    79.126653       81.126920       85.814697       87.522874       79.700167
    71.804414       64.544103       57.713709       51.440481       45.963414
    41.375492       37.494574       33.285370
```

C.1.3 Boeing Rig, Vane Geometry File

```
BOEING NOISE RESEARCH FAN ROTOR AIRFOIL DATA
   25
 XLE
     4.444516        4.621318        4.797917        4.974300        5.150474
     5.326517        5.502514        5.678491        5.854412        6.030246
     6.205996        6.381669        6.557270        6.732800        6.908259
     7.083648        7.258973        7.434238        7.609443        7.784592
     7.959685        8.134723        8.309708        8.484640        8.659533
 YLE
     -.521443        -.512240        -.503283        -.494939        -.487390
     -.480031        -.472047        -.463123        -.453707        -.444241
     -.434797        -.425355        -.415957        -.406676        -.397607
     -.388840        -.380399        -.372308        -.364638        -.357478
```

```
    -.350920        -.345039        -.339930        -.335719        -.332129
ZLE
    33.558464       33.551719       33.545323       33.539482       33.534258
    33.529211       33.523811       33.517896       33.511798       33.505812
    33.499986       33.494304       33.488786       33.483468       33.478388
    33.473574       33.469021       33.464721       33.460687       33.456934
    33.453476       33.450314       33.447460       33.444927       33.442591
BETA1
    54.377055       54.956615       55.496653       55.957781       56.321473
    56.655262       57.047177       57.528590       58.049527       58.561855
    59.057595       59.539306       60.002626       60.440277       60.842064
    61.198488       61.506767       61.764938       61.965412       62.098746
    62.154838       62.126665       62.004202       61.771489       61.461663
XTE
     4.449688        4.626422        4.802974        4.979351        5.155568
     5.331666        5.507683        5.683635        5.859512        6.035303
     6.211015        6.386653        6.562220        6.737721        6.913157
     7.088532        7.263849        7.439113        7.614324        7.789486
     7.964601        8.139671        8.314697        8.489683        8.664629
YTE
      .475292         .463891         .452492         .441234         .430168
      .418995         .407329         .395015         .382252         .369235
      .355987         .342490         .328754         .314802         .300660
      .286336         .271821         .257111         .242207         .227107
      .211805         .196305         .180614         .164646         .148411
ZTE
    34.973038       34.980243       34.987208       34.993882       35.000271
    35.006563       35.012960       35.019511       35.026069       35.032508
    35.038799       35.044942       35.050921       35.056718       35.062316
    35.067708       35.072895       35.077874       35.082642       35.087198
    35.091547       35.095686       35.099617       35.103363       35.106910
BETA2
    63.044815       63.938711       64.836718       65.742298       66.660284
    67.595264       68.550815       69.529029       70.529018       71.550060
    72.592986       73.659331       74.749669       75.865051       77.007562
    78.179898       79.384721       80.623190       81.898540       83.215142
    84.578259       85.990699       87.455907       88.989549       89.424262
```

Appendix D.—Turbulence Spectra, GE R4 and M5 Fans

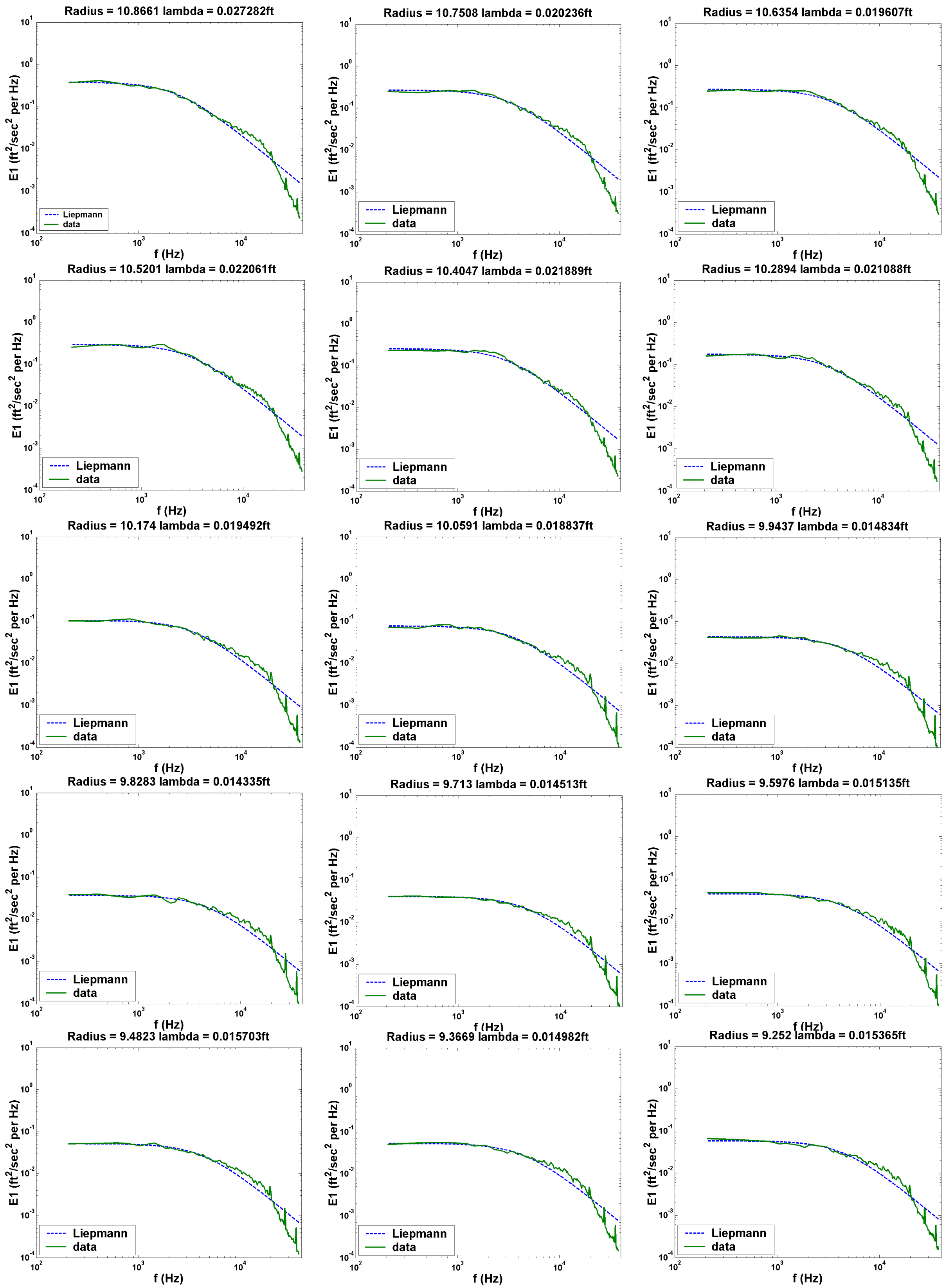
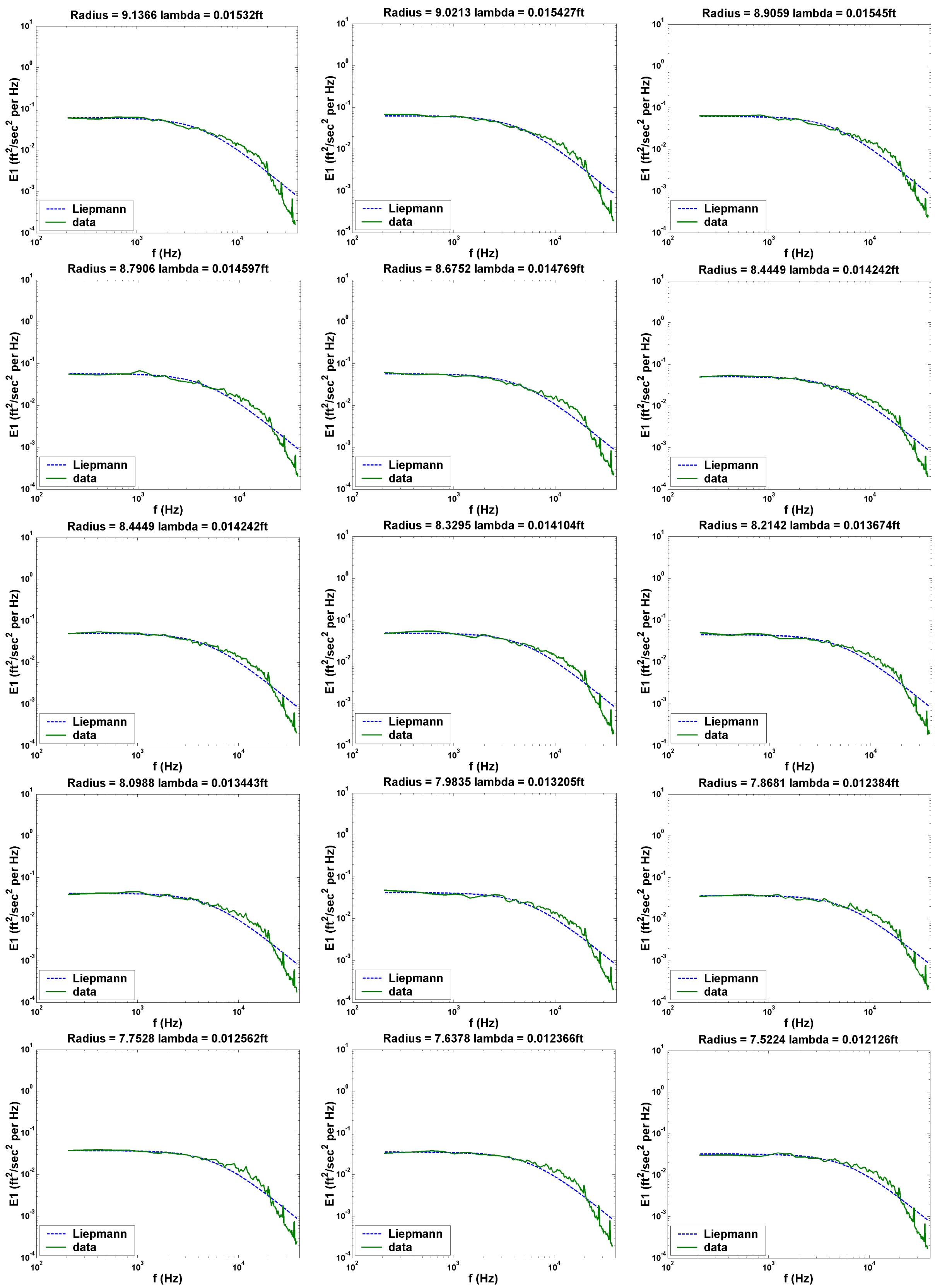


Figure D.1.—Source diagnostic test, R4 fan, approach, station A.



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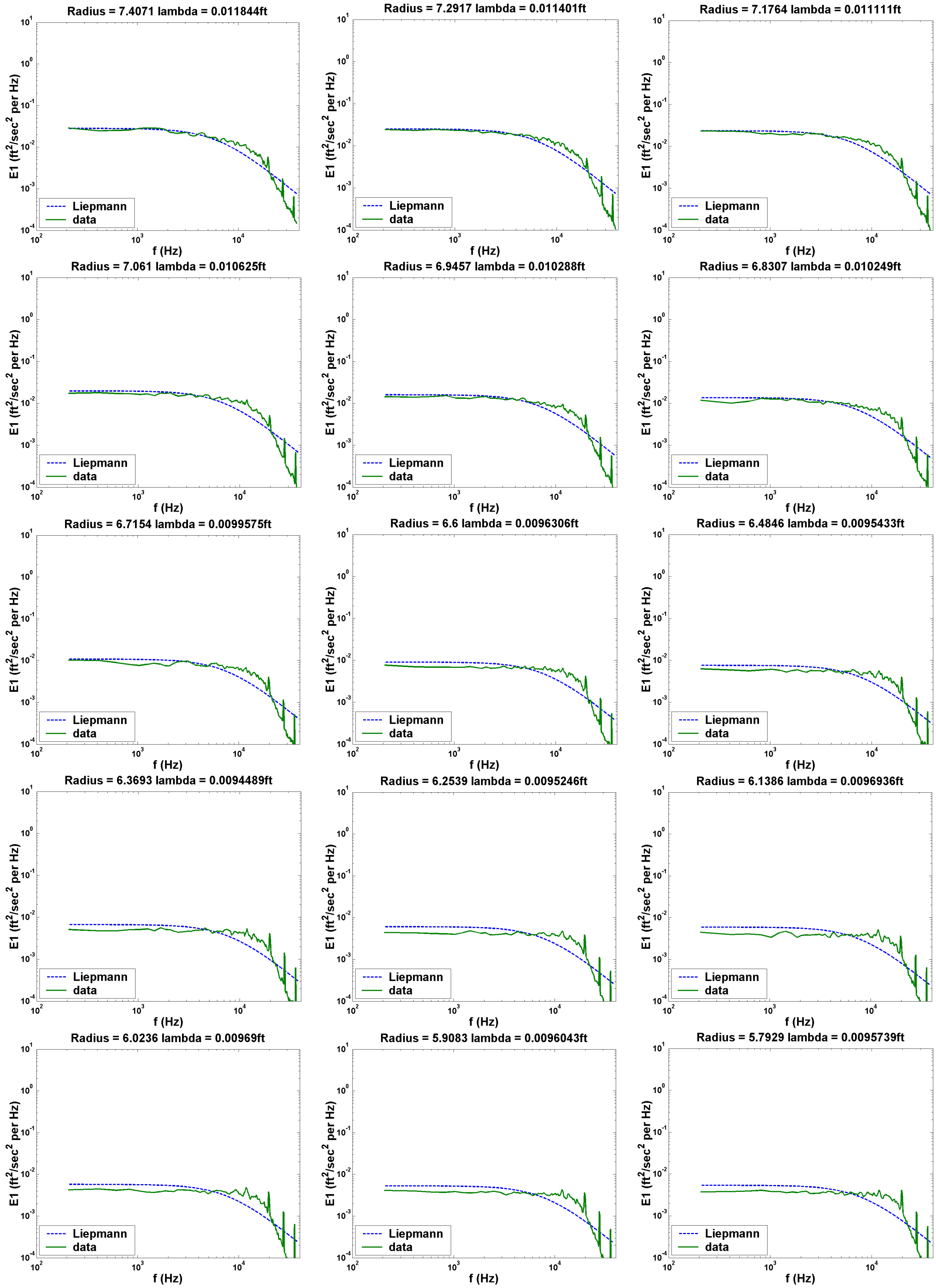

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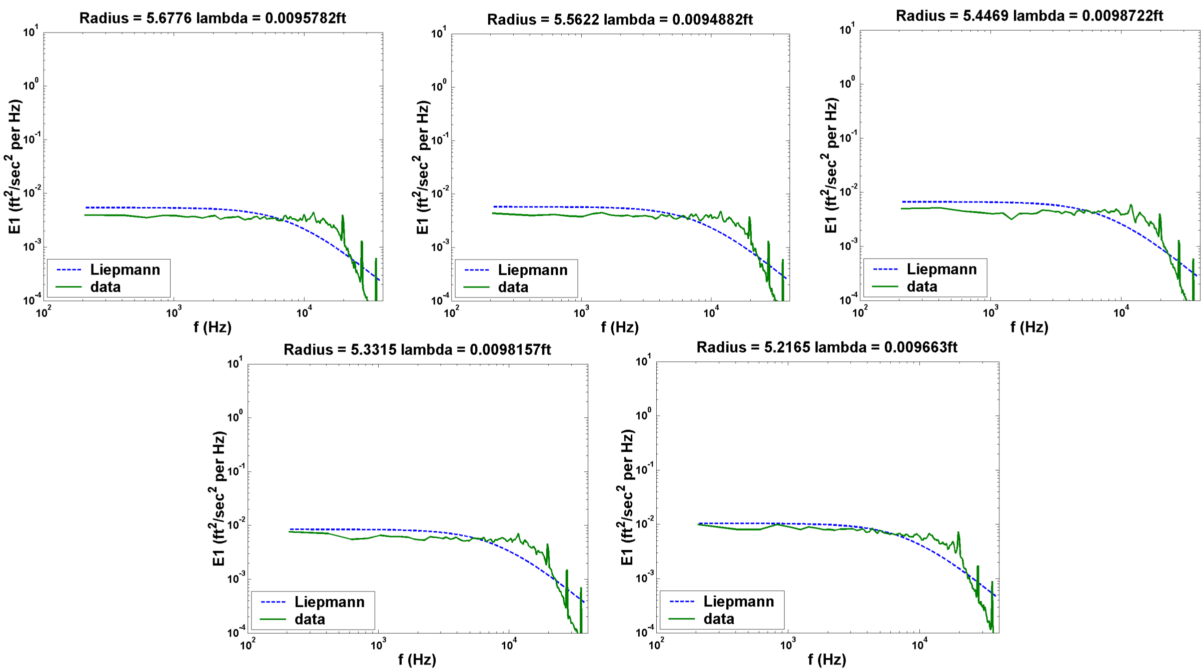

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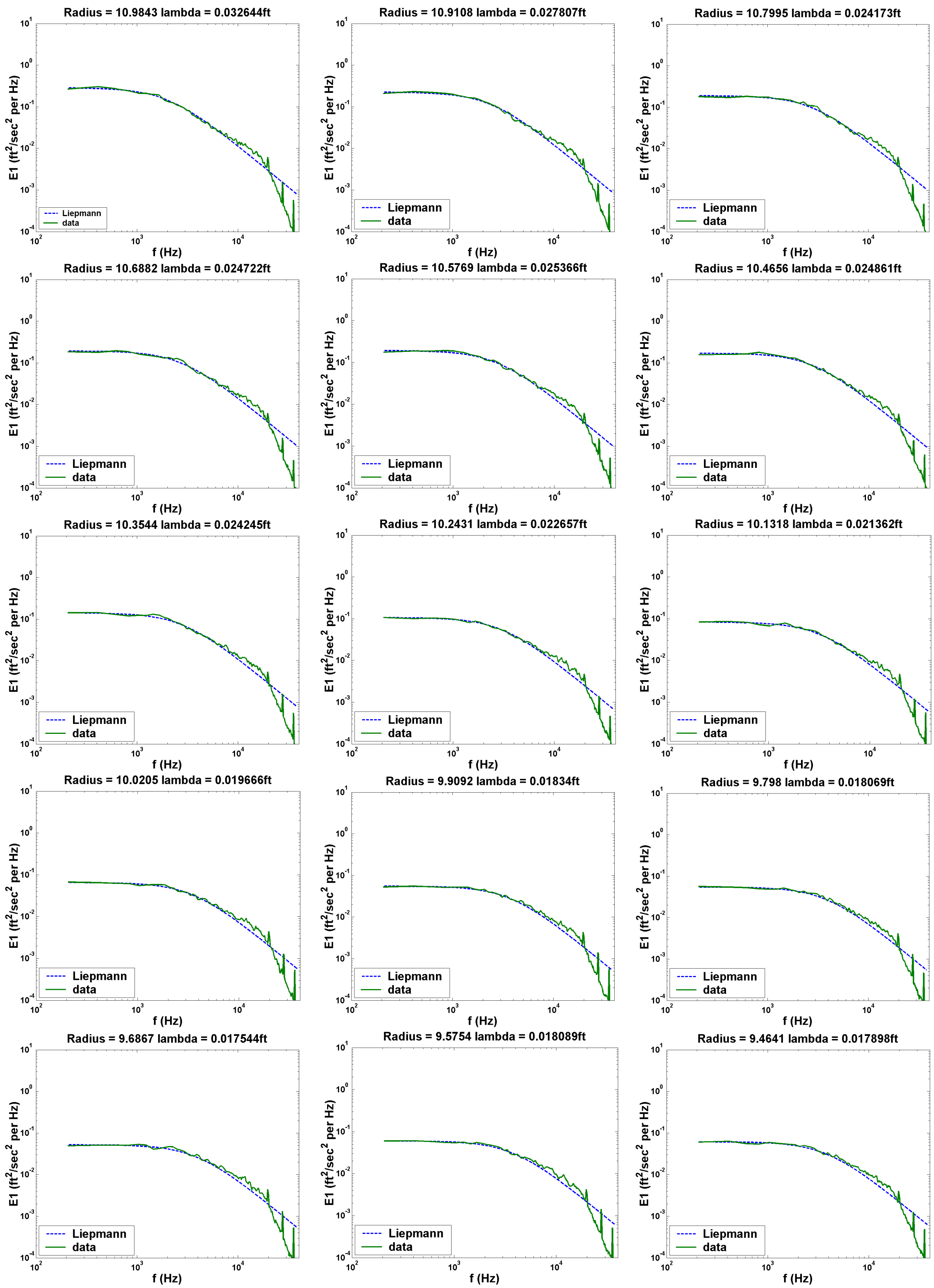
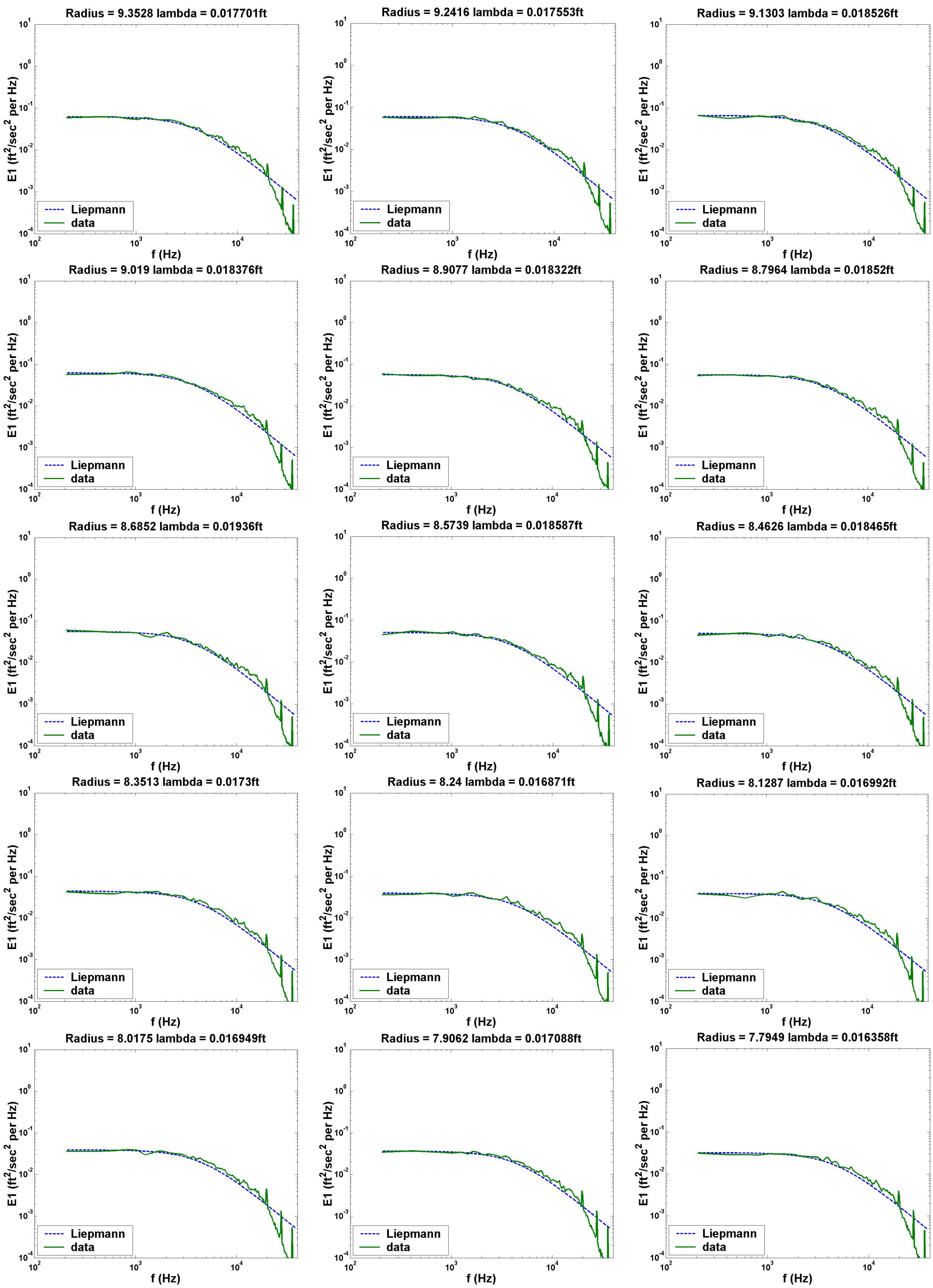


Figure D.2.—Source diagnostic test, R4 fan, approach, station B.



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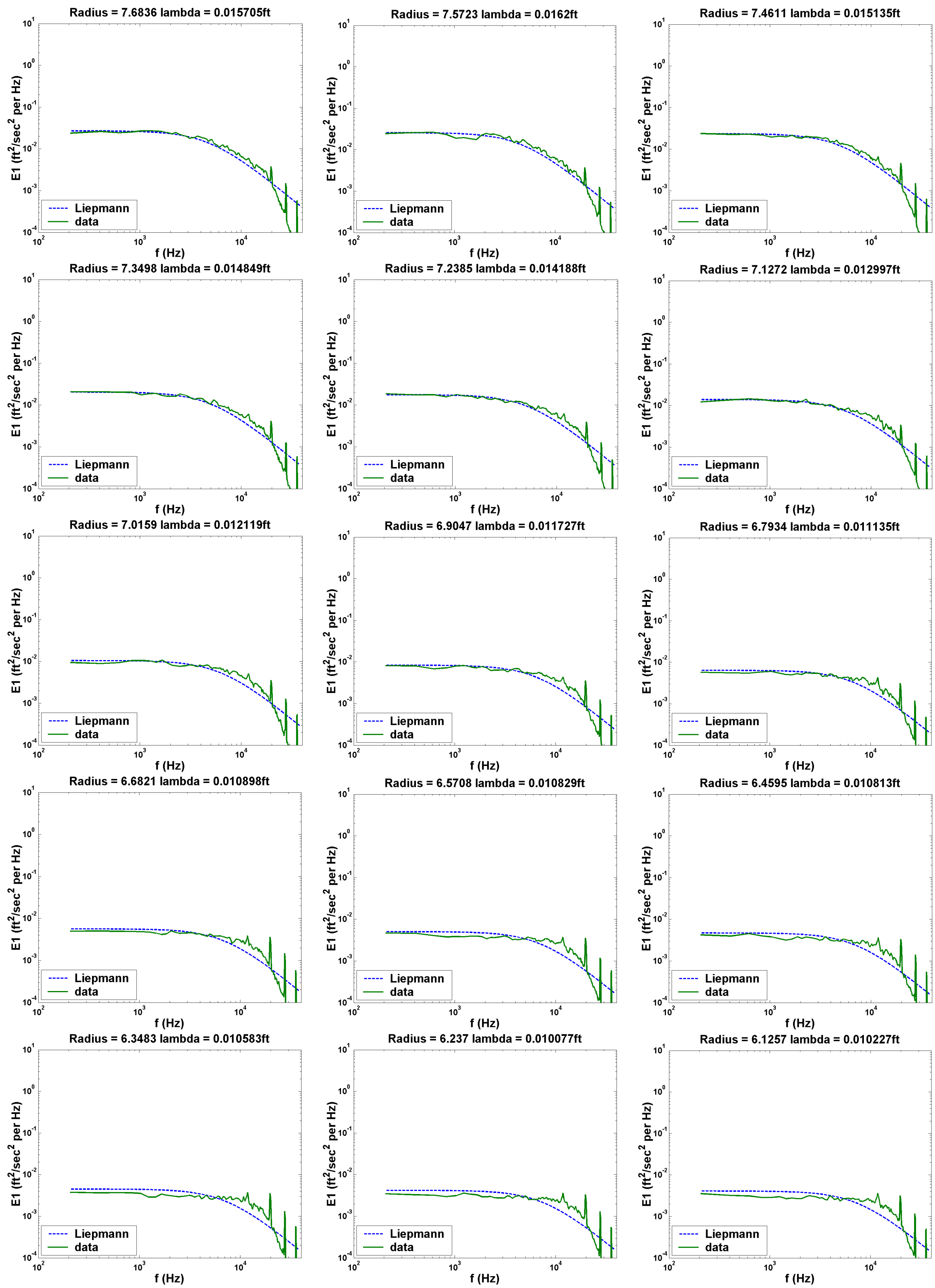

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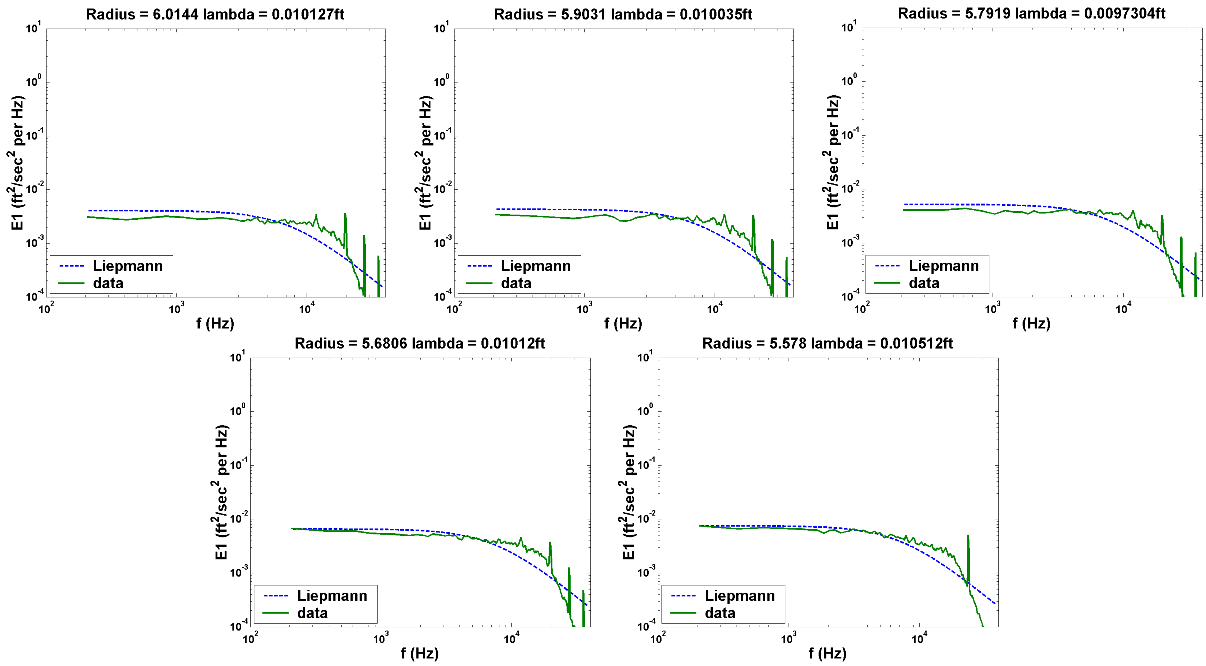

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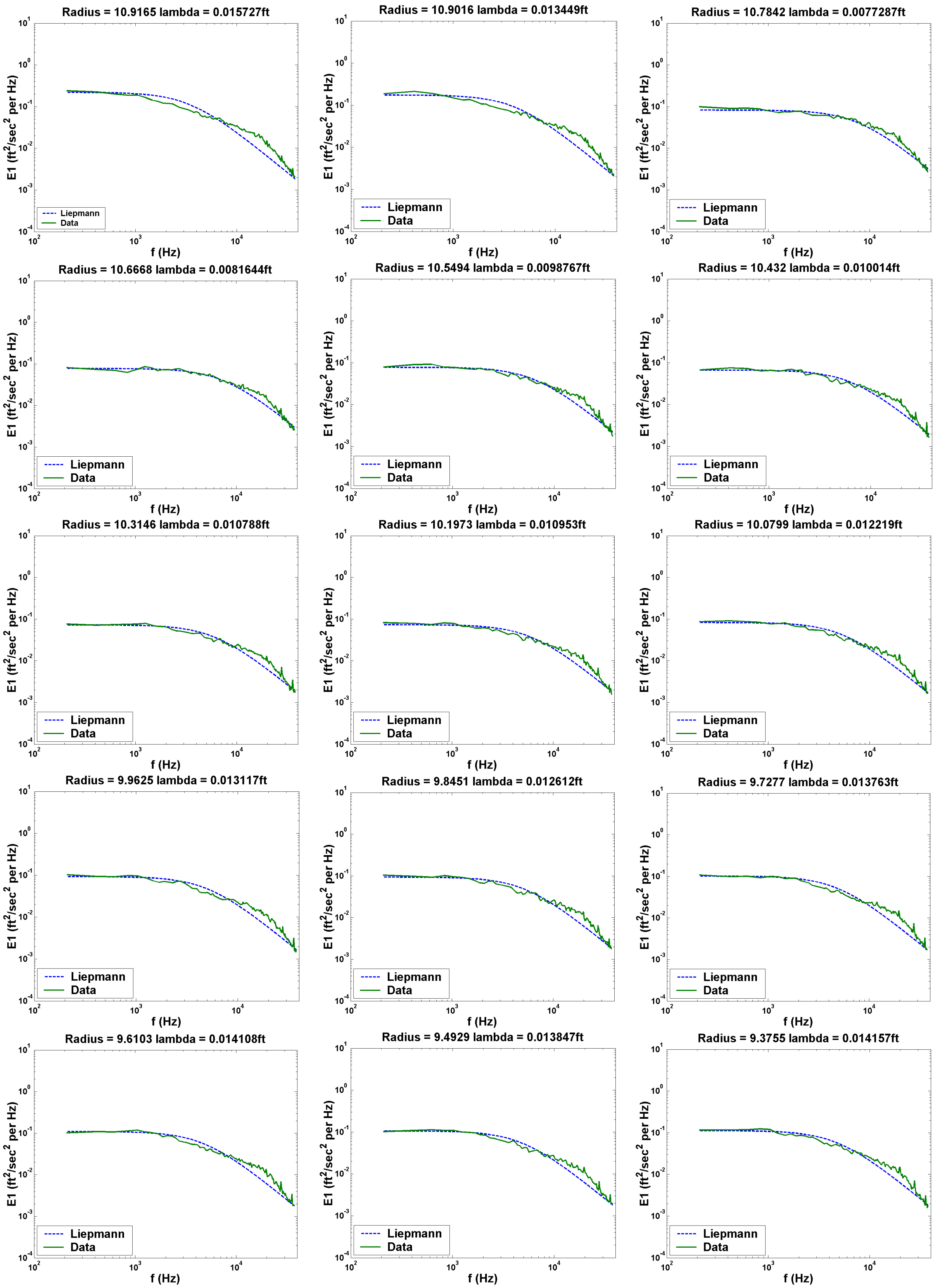
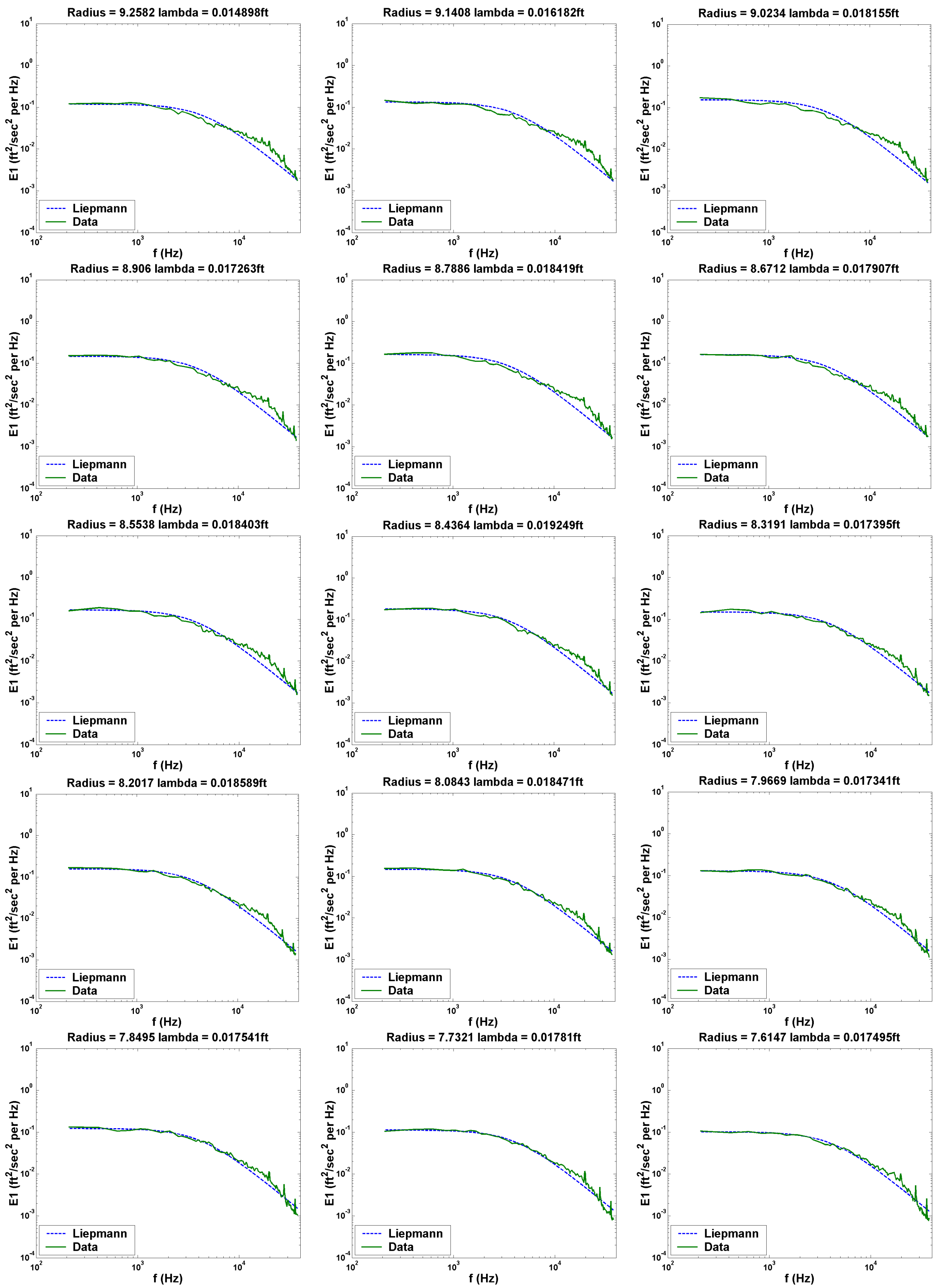


Figure D.3.—Source diagnostic test, M5 fan, approach, station A.



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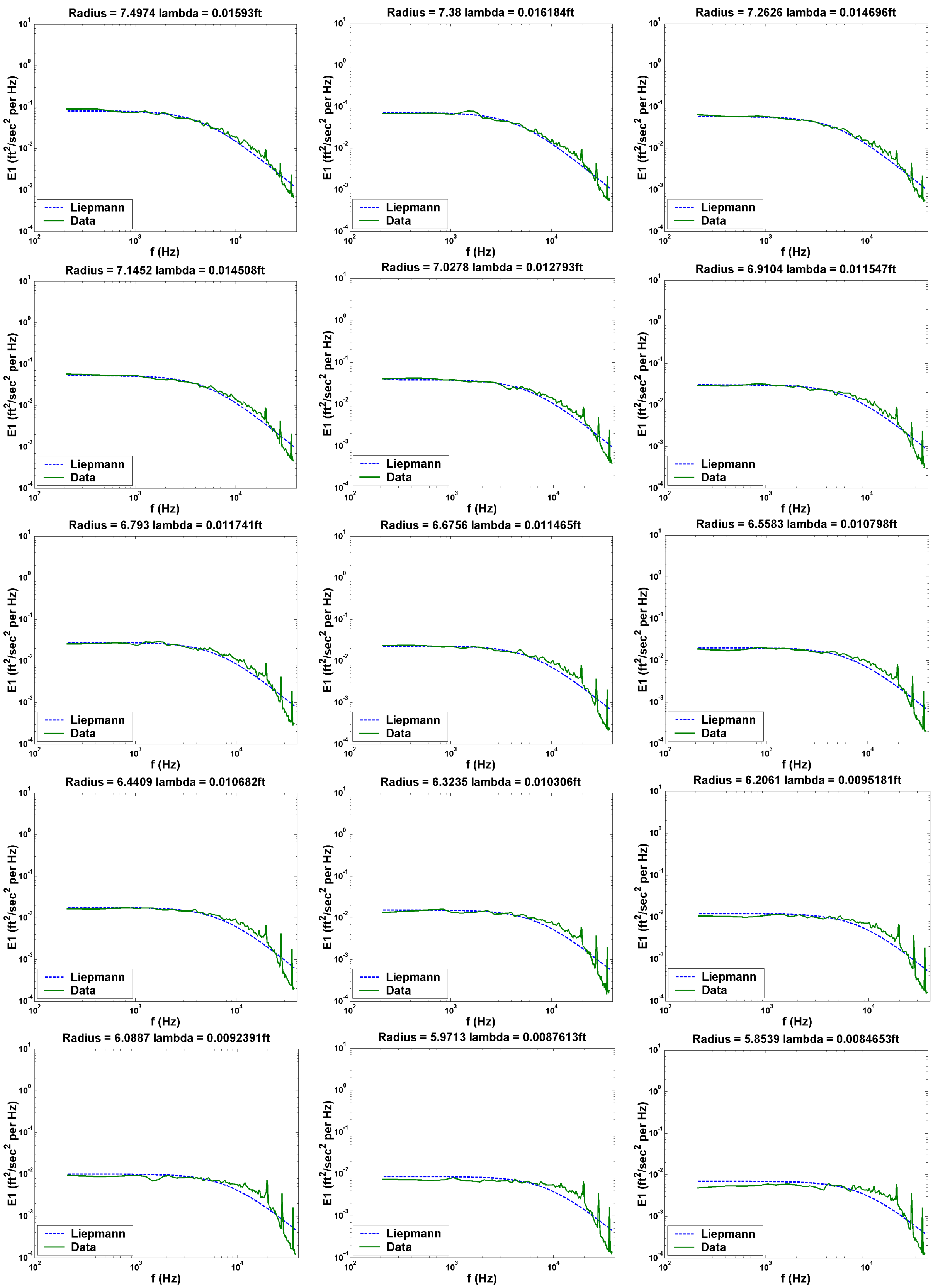

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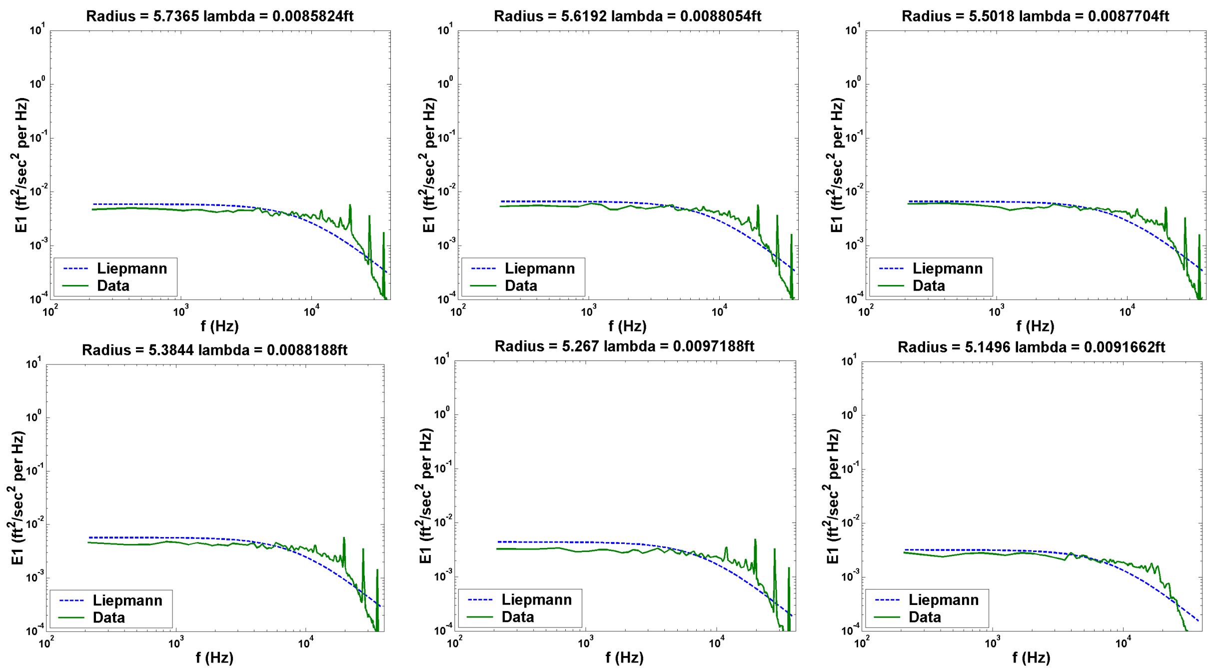

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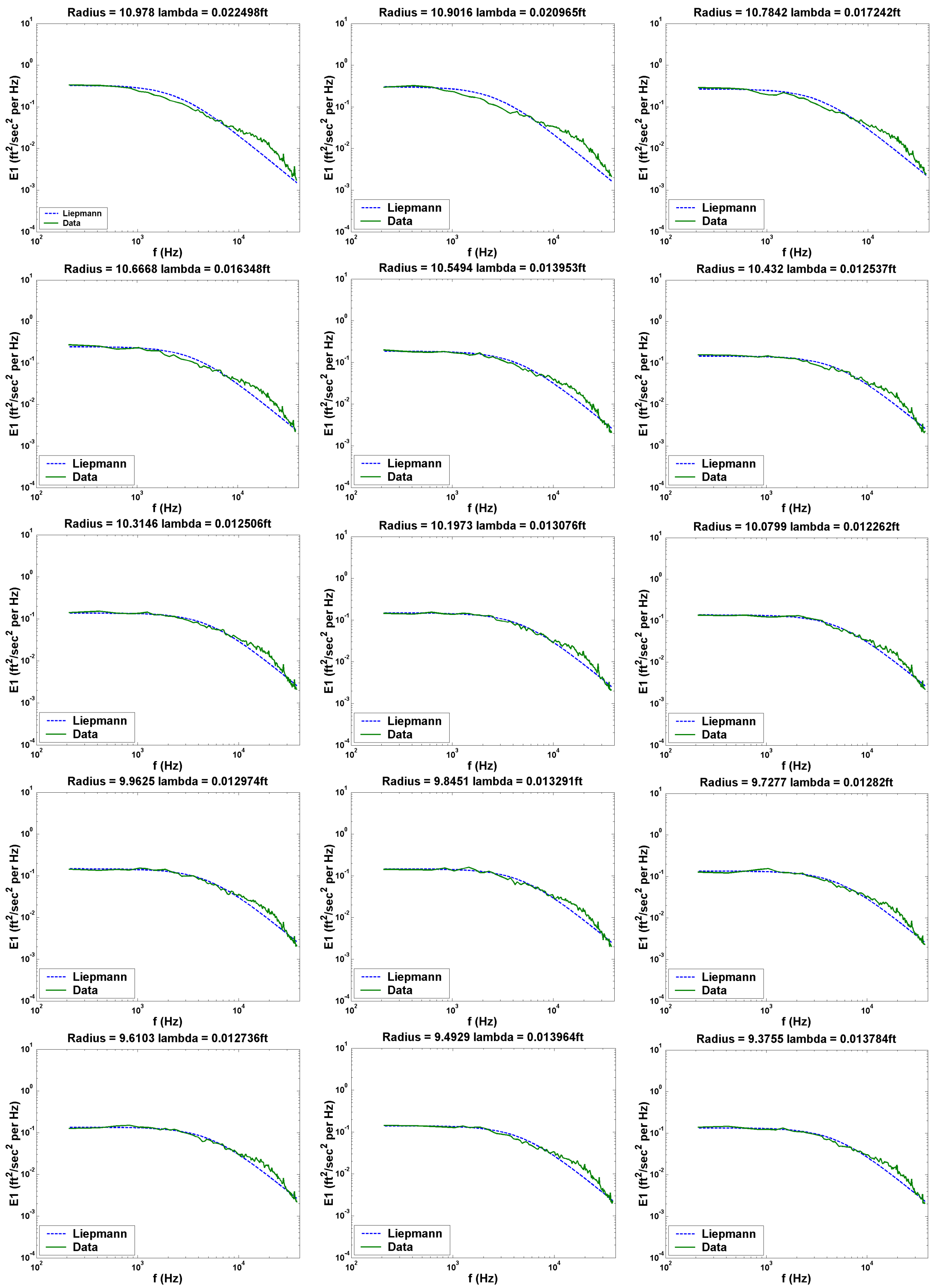
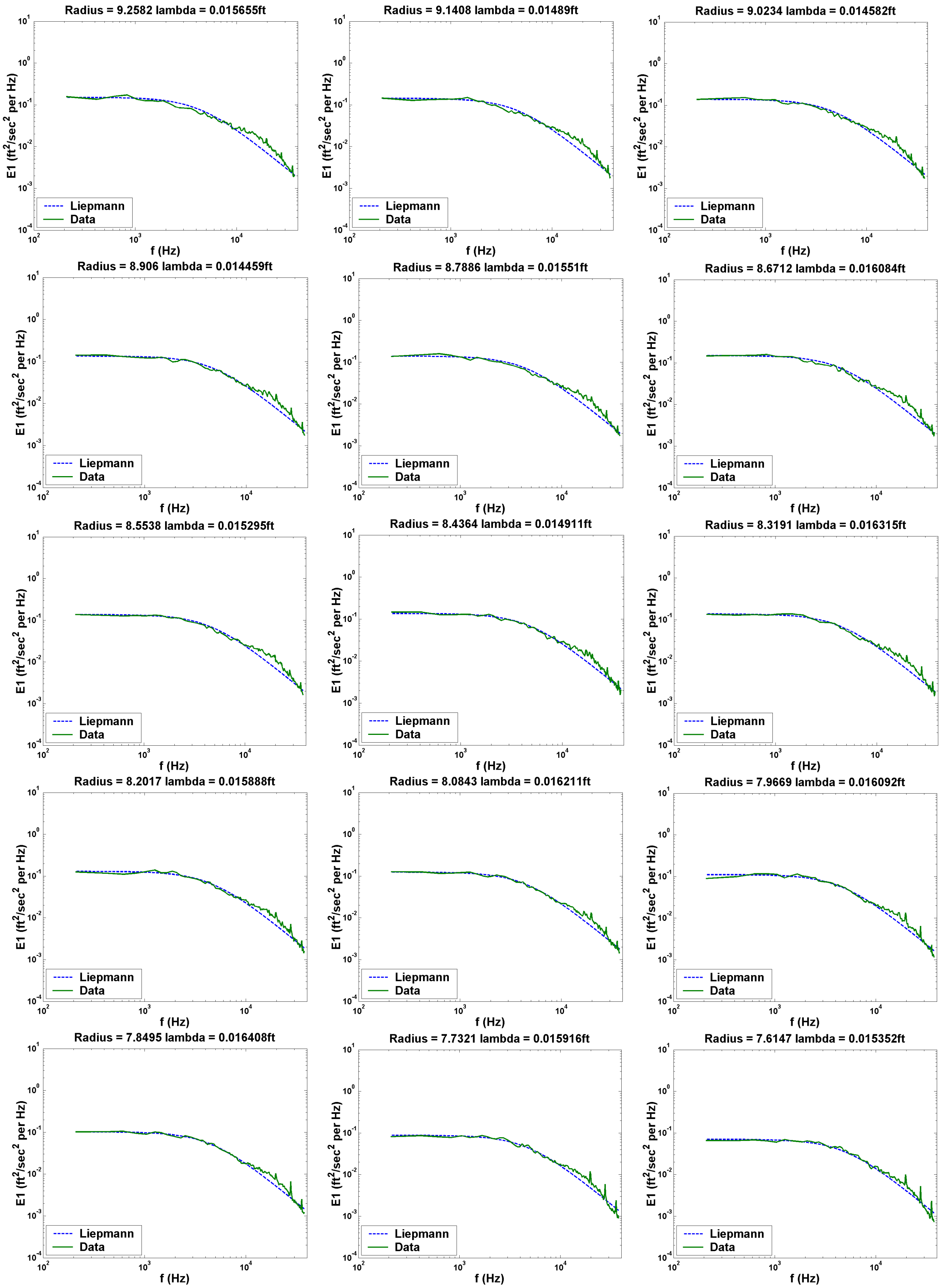


Figure D.4.—Source diagnostic test, M5 fan, approach, station B.



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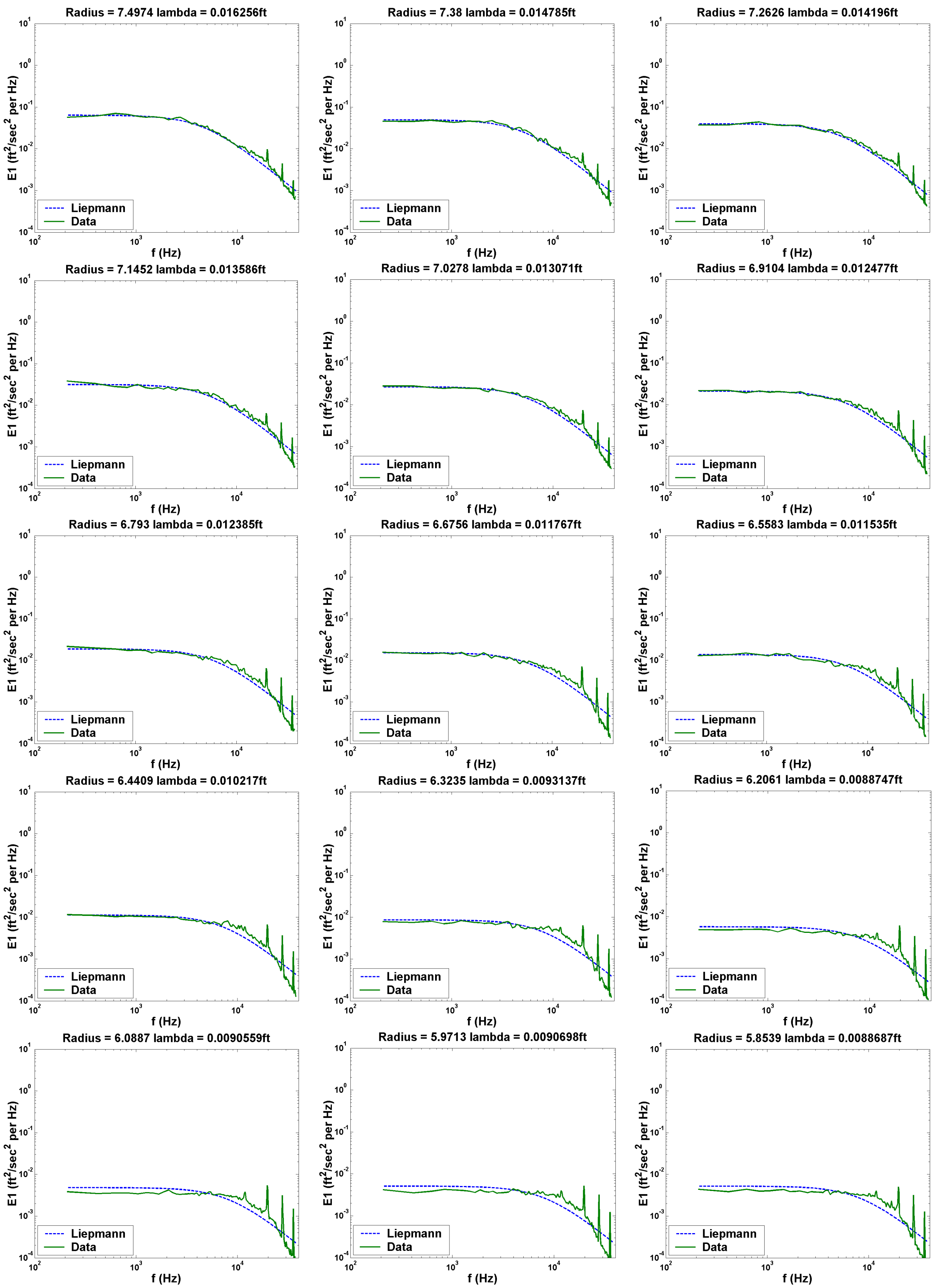

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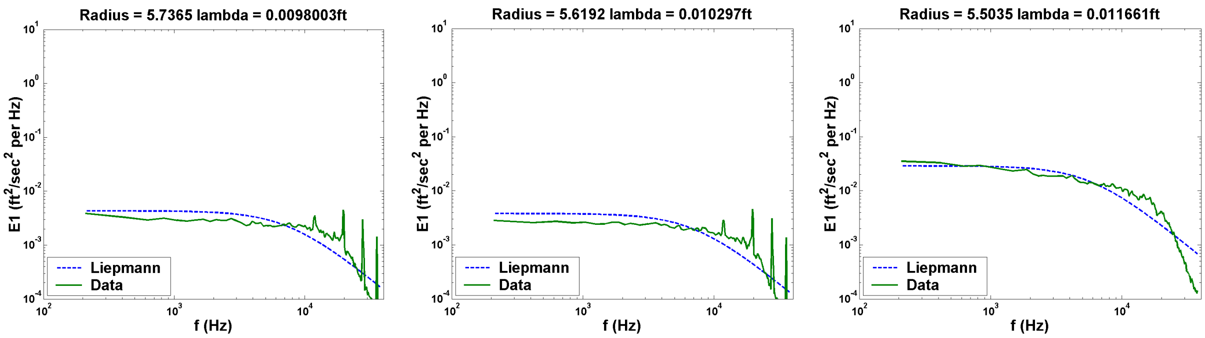

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Appendix E.—Turbulence Spectra, P&W Fan Numbers 1 and 2

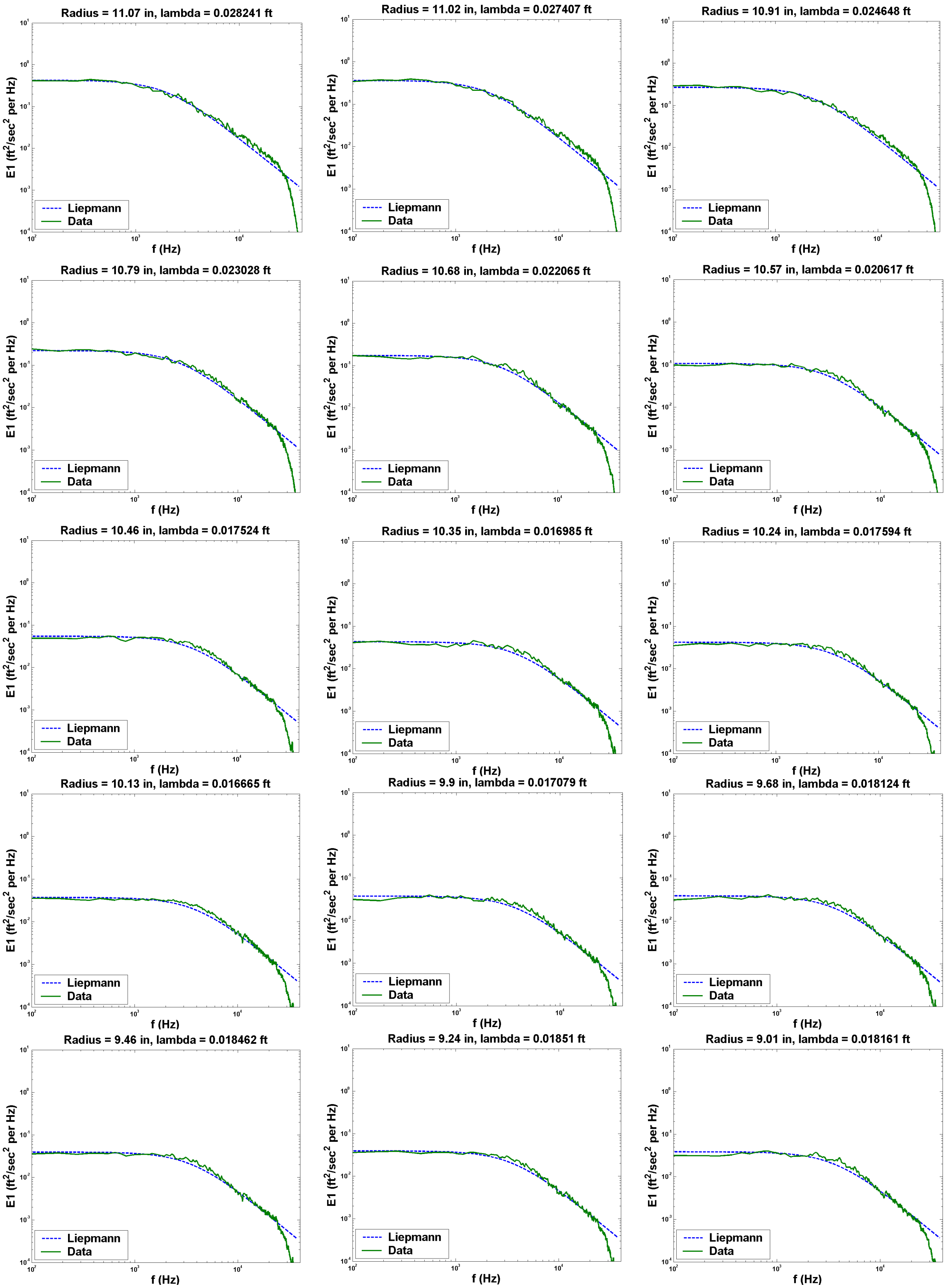
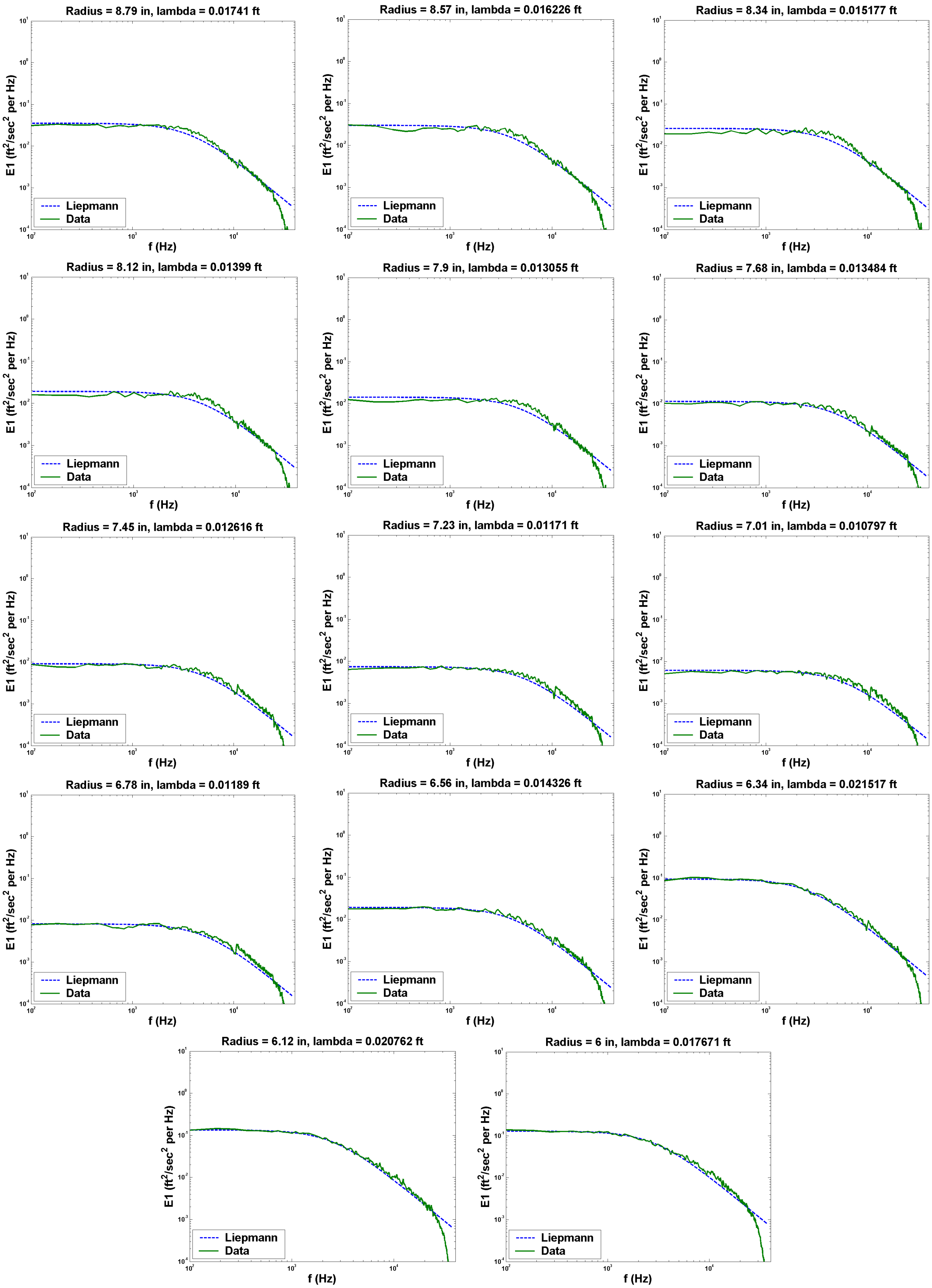


Figure E.1.—P&W fan number 1 test, approach, station A.



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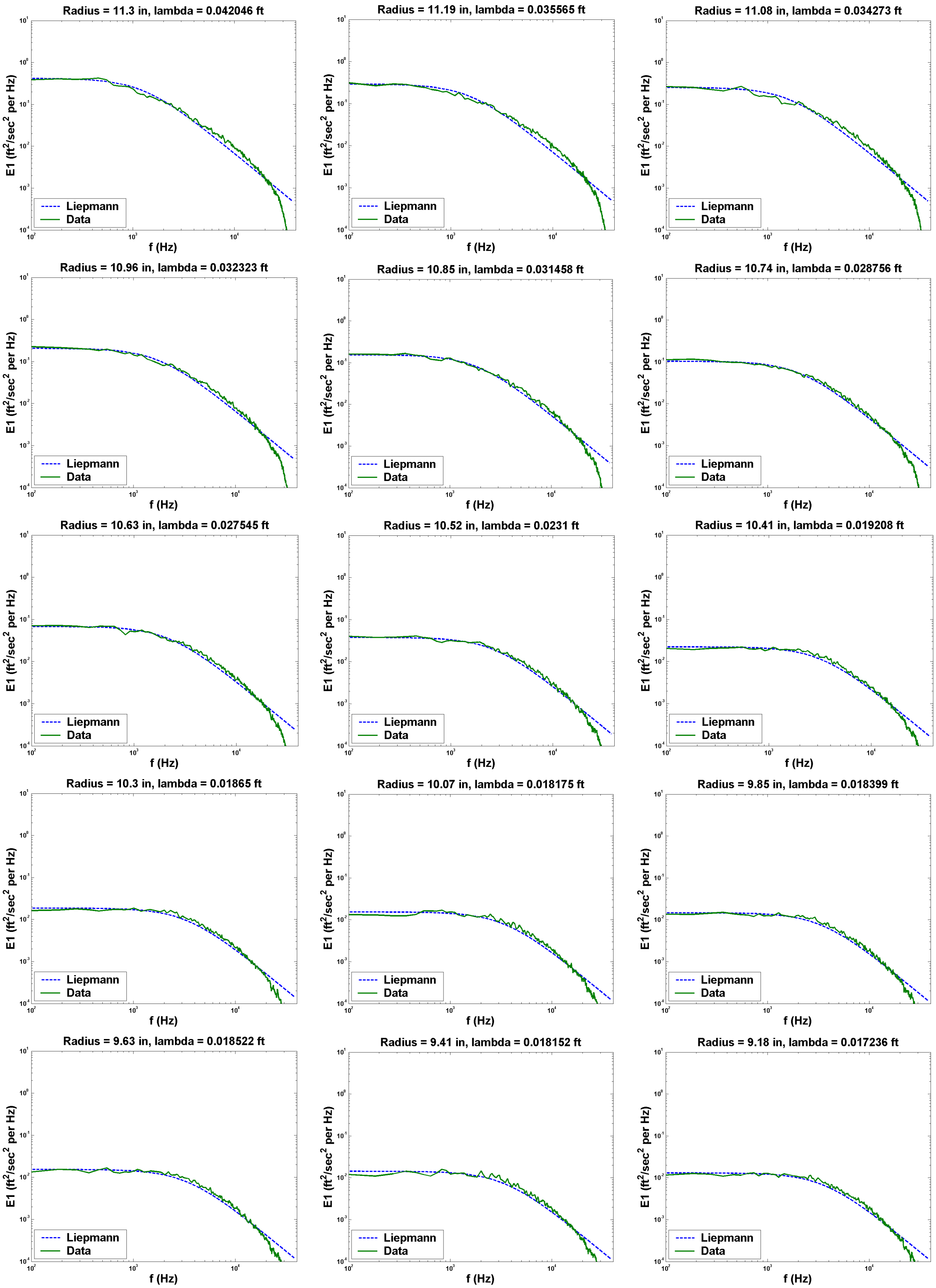
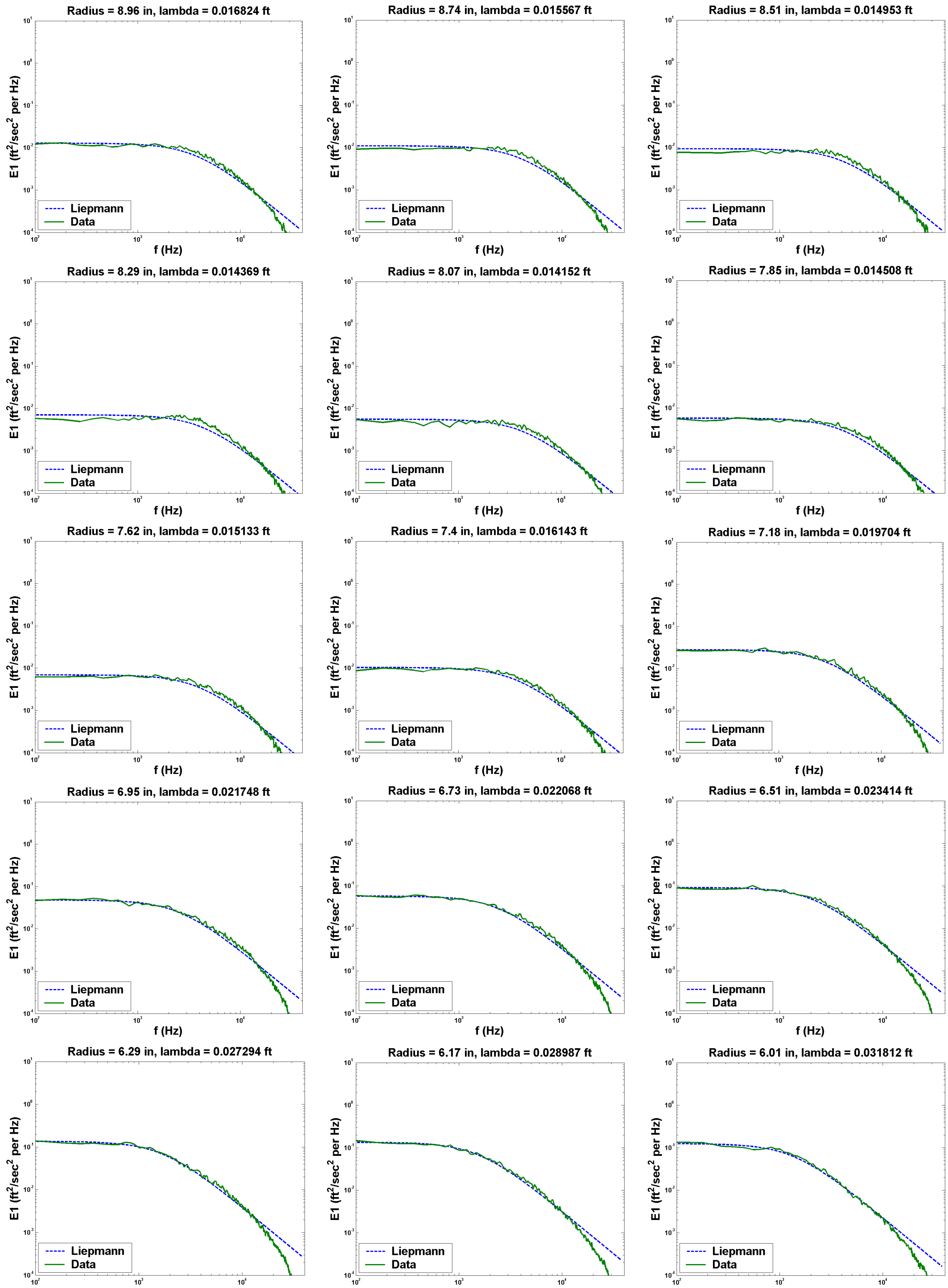


Figure E.2.—P&W fan number 1 test, approach, station B.



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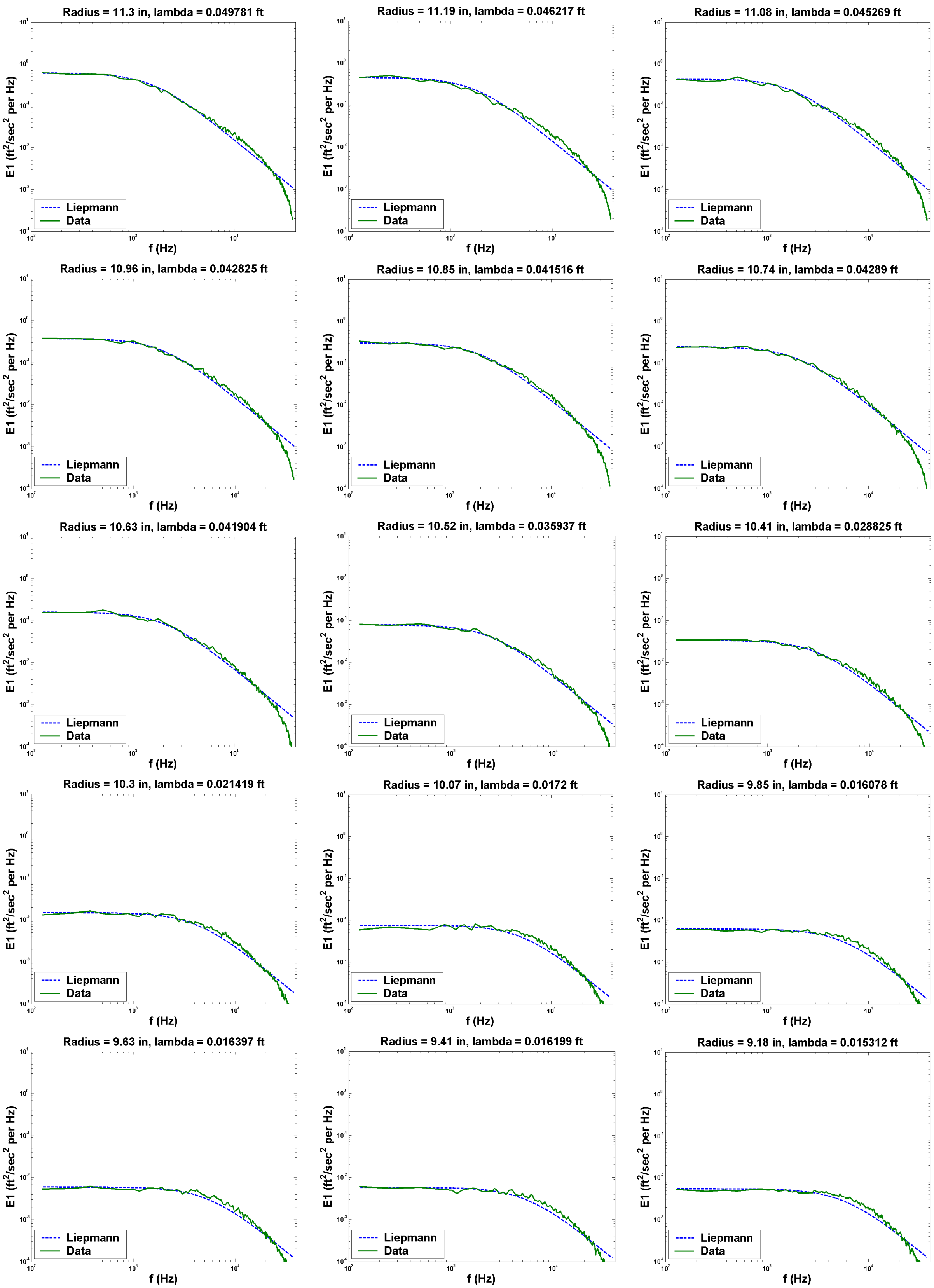
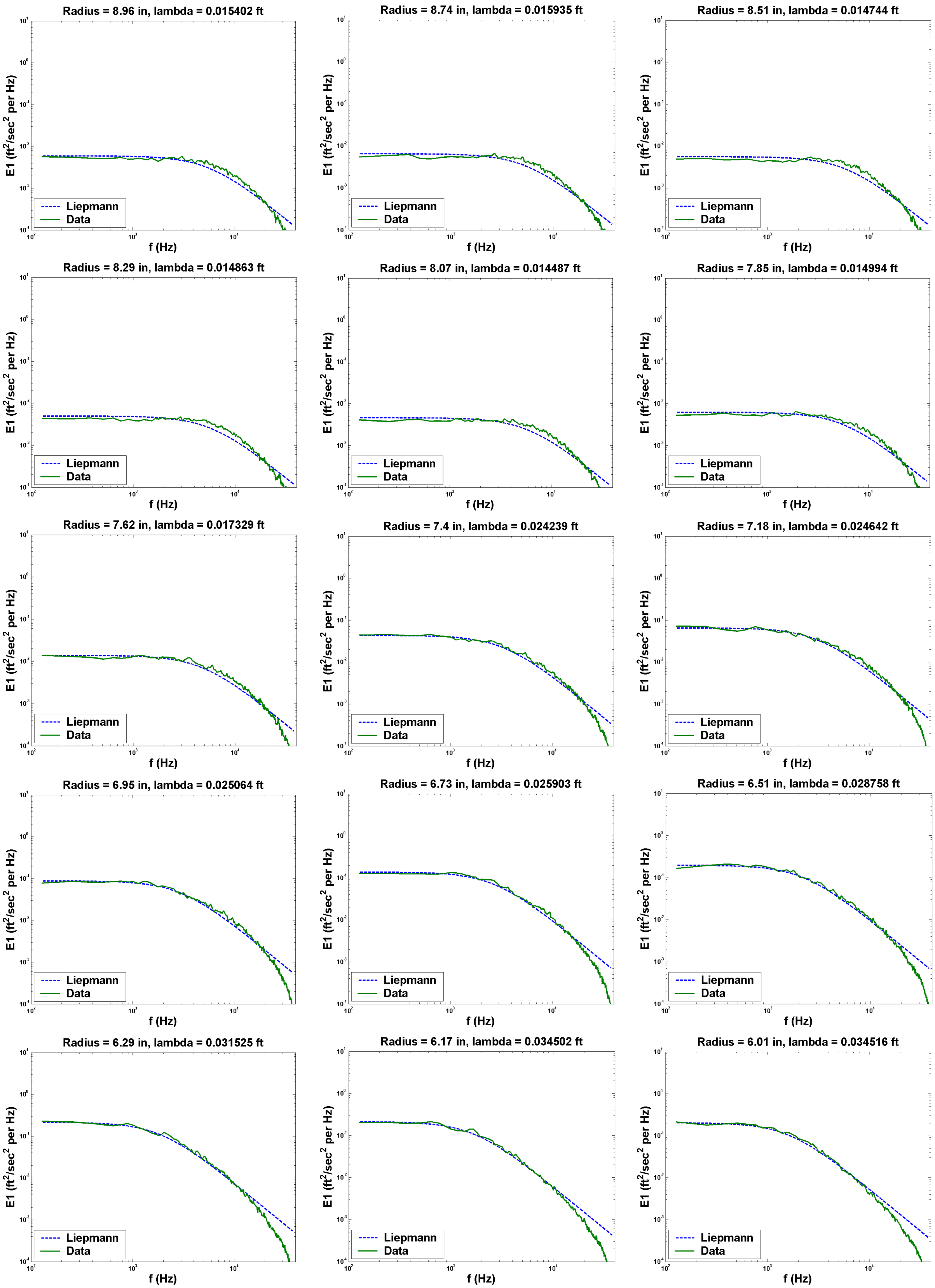


Figure E.3.—P&W fan number 1 test, cutback, station B.



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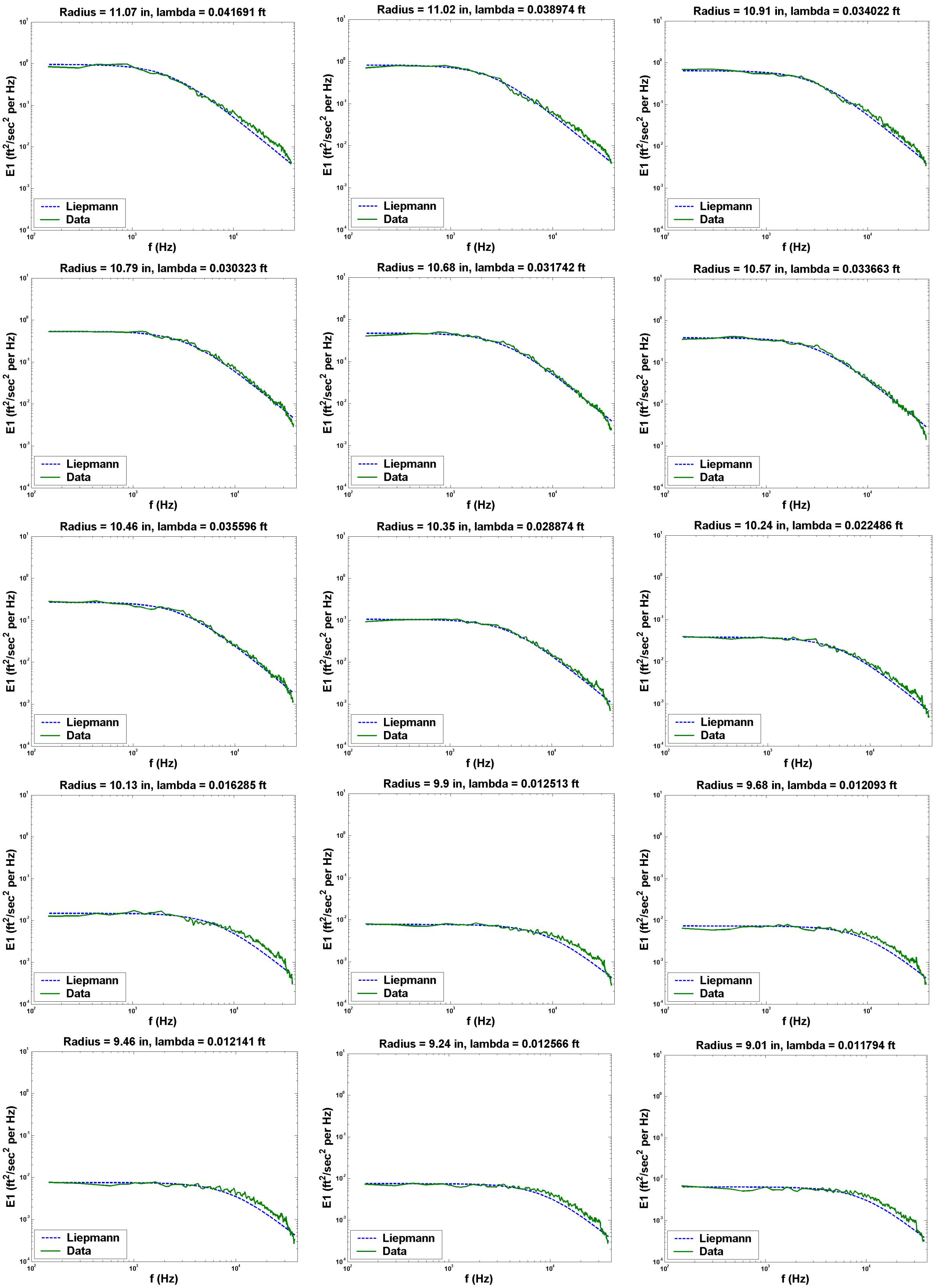
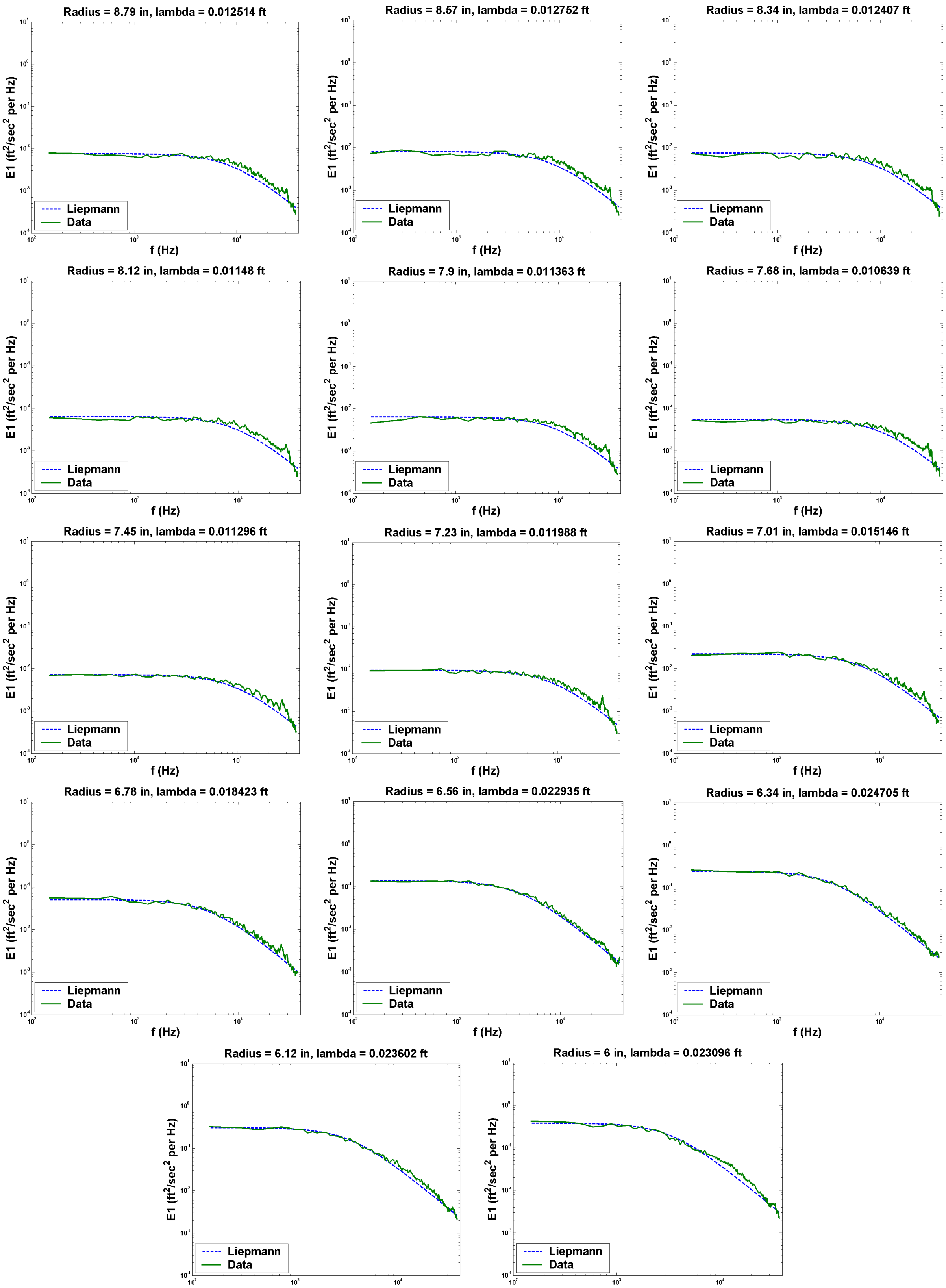


Figure E.4.—P&W fan number 1 test, sideline, station A.



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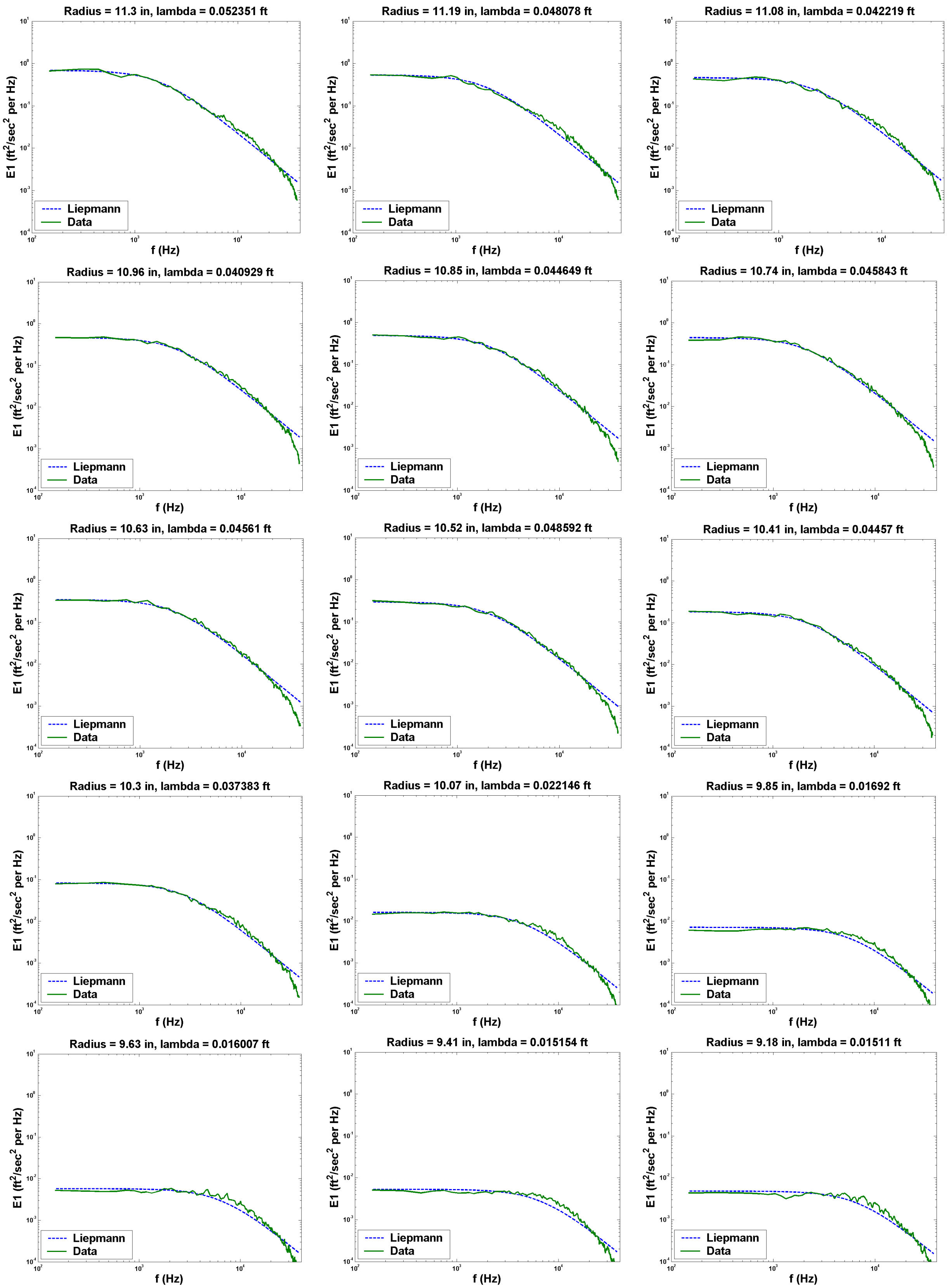
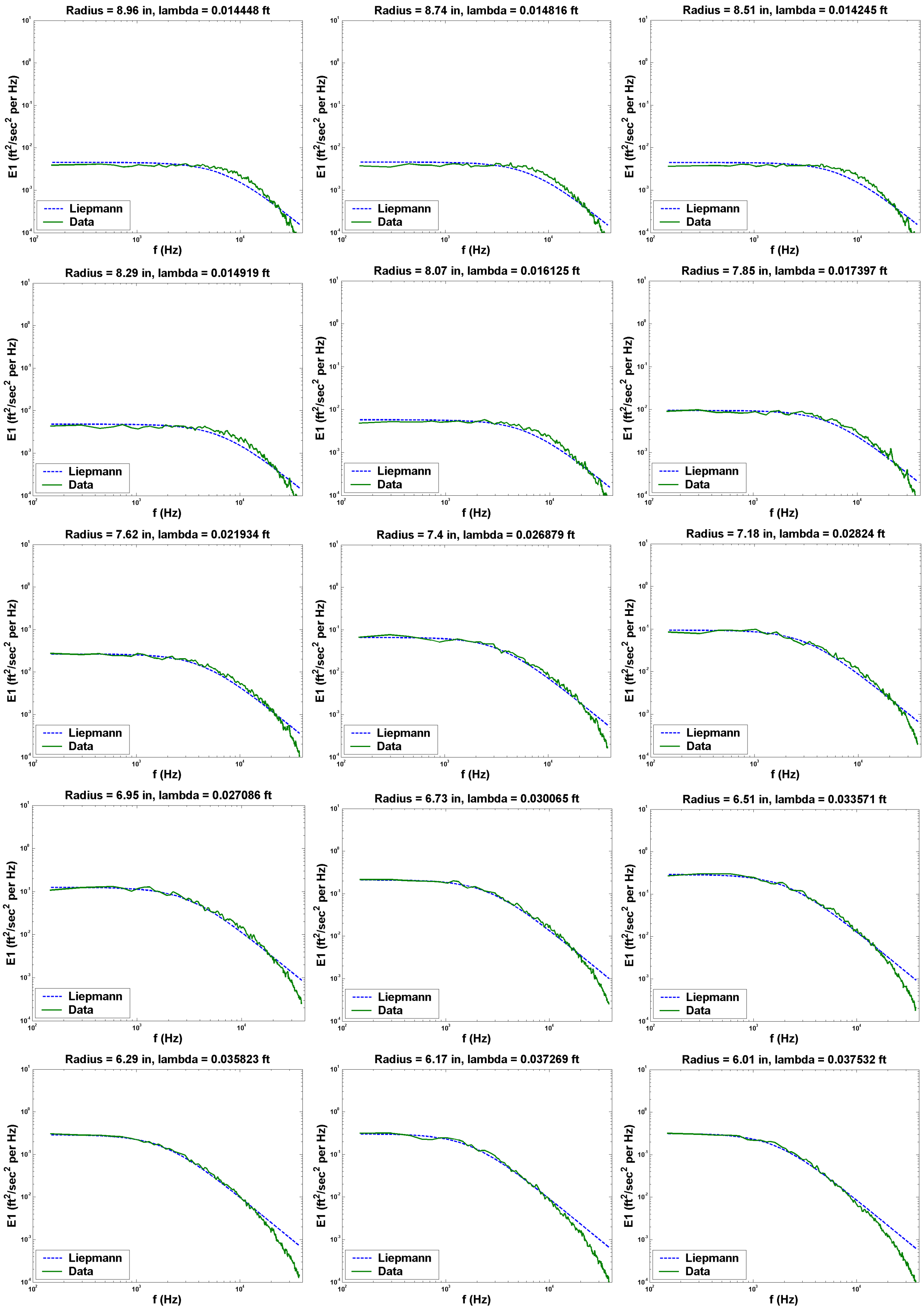


Figure E.5.—P&W fan number 1 test, sideline, station B.



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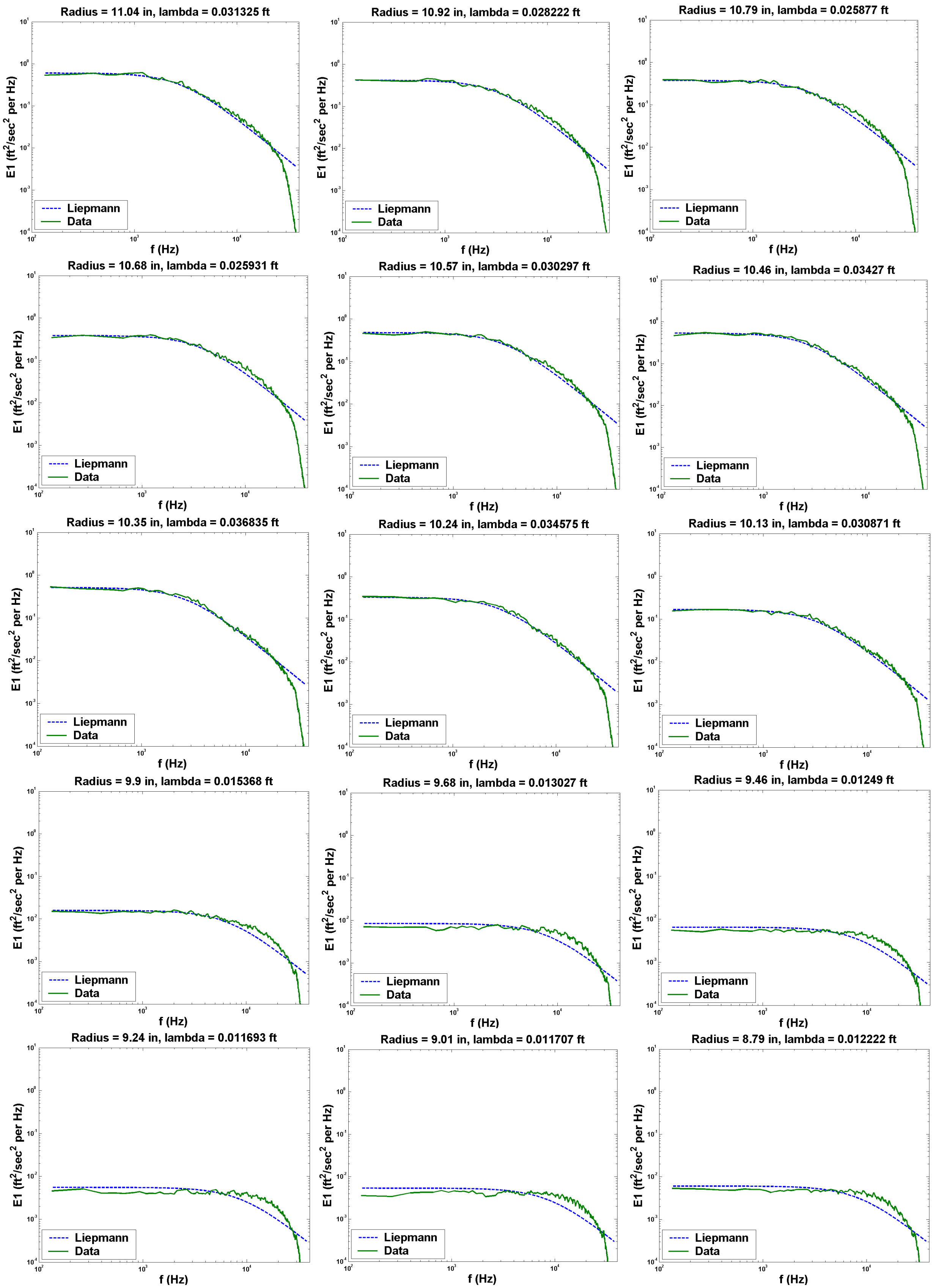

Figure E.6.—P&W fan number 2 test, sideline, station A.

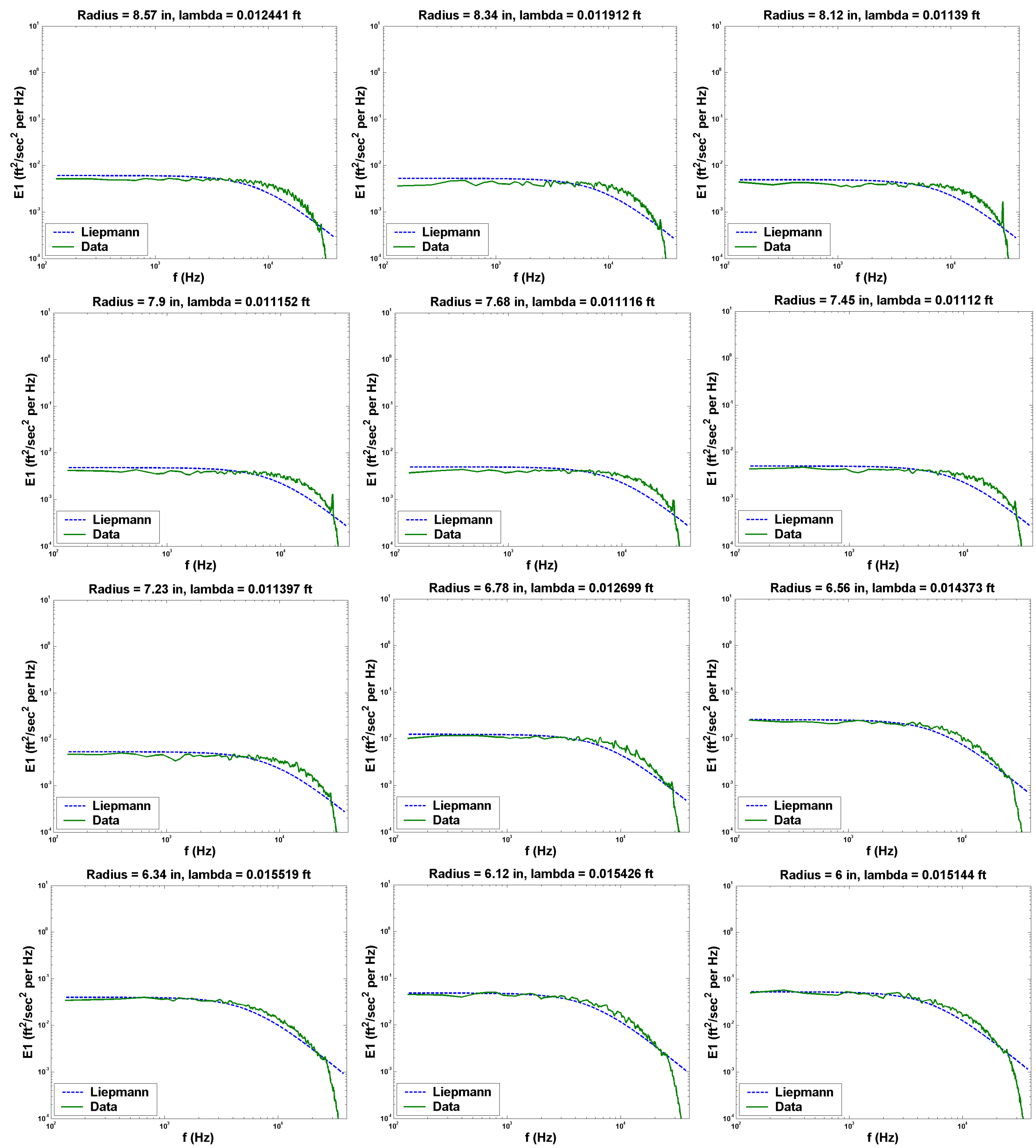

Figure E.6.—Concluded.

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1. REPORT DATE *(DD-MM-YYYY)*
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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Pratt & Whitney has developed a Broadband Fan Noise Prediction System (BFaNS) for turbofan engines. This system computes the noise generated by turbulence impinging on the leading edges of the fan and fan exit guide vane, and noise generated by boundary-layer turbulence passing over the fan trailing edge. BFaNS has been validated on three fan rigs that were tested during the NASA Advanced Subsonic Technology Program (AST). The predicted noise spectra agreed well with measured data. The predicted effects of fan speed, vane count, and vane sweep also agreed well with measurements. The noise prediction system consists of two computer programs: Setup_BFaNS and BFaNS. Setup_BFaNS converts user-specified geometry and flow-field information into a BFaNS input file. From this input file, BFaNS computes the inlet and aft broadband sound power spectra generated by the fan and FEGV. The output file from BFaNS contains the inlet, aft and total sound power spectra from each noise source. This report is the third volume of a three-volume set documenting the Broadband Fan Noise Prediction System: Volume 1: Setup_BFaNS User's Manual and Developer's Guide; Volume 2: BFaNS User's Manual and Developer's Guide; and Volume 3: Validation and Test Cases. The present volume begins with an overview of the Broadband Fan Noise Prediction System, followed by validation studies that were done on three fan rigs. It concludes with recommended improvements and additional studies for BFaNS.

15. SUBJECT TERMS
Fan blades; Vanes; Broadband; Turbulence; Rotor stator interactions

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